MINING METHODS AND COSTS AT THE ANACONDA COMPANY BERKELEY PIT, BUTTE, MONT.

BY JOHN R. MCWILLIAMS

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MINING METHODS AND COSTS AT THE ANACONDA COMPANY BERKELEY PIT, BUTTE, MONT.[1/]

by

John R. McWilliams[2/]

SUMMARY AND INTRODUCTION

This report is one of a series published by the Bureau of Mines describing methods and practices at various mines throughout the United States. A previous program, conducted from 1928 to 1939, was well received by the mining industry and technical institutions and provided much source material for engineering textbooks and technical handbooks. The stringent wartime demands on the mining industry, the rapidly changing postwar economic situation, and greatly accelerated technologic growth have combined to render many of the previous data obsolete. The objective of the present program is to assemble reliable technical information on mining methods and practices throughout the country and present it for the use of the mining industry, technical schools, textbook authors, and other interested persons.

This report deals with the design and development of the Berkeley open-pit mine at Butte, Mont., owned and operated by The Anaconda Company. The Berkeley pit is but one facet of a well-organized and integrated copper-mining operation involving the entire Butte district. Vein-type mining, important for 75 years, is still in progress at depths from 600 feet to nearly 1 mile; on intermediate levels, low-grade ore left untouched by earlier vein-type mines is being extracted by block caving entire ore zones,[3/] and secondarily enriched but lower grade near-surface portions of the same ore zones are being mined by open-pit operations (fig. 1). The Berkeley pit itself is named for the Berkeley mine, one of the old mines that extracted copper ore from high-grade veins in the area that now will be mined by open-pit methods.

Near-surface enrichment of a portion of the Butte Hill has been recognized for many years, but until recently the possibility of mining the entire zone was not formally considered. With increasing emphasis on large-scale mining of low-grade deposits, thorough examination of the enriched zone seemed justified. Preliminary development headings from existing shafts in the area,

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1/ Work on manuscript completed April 1958.
2/ Mining engineer, Bureau of Mines, Region I, Spokane, Wash.
3/ Popoff, C. C., Block Caving of Kelley Mine, The Anaconda Company, Butte, Mont.: Bureau of Mines Inf. Circ. 7758, 1956, 102 pp.

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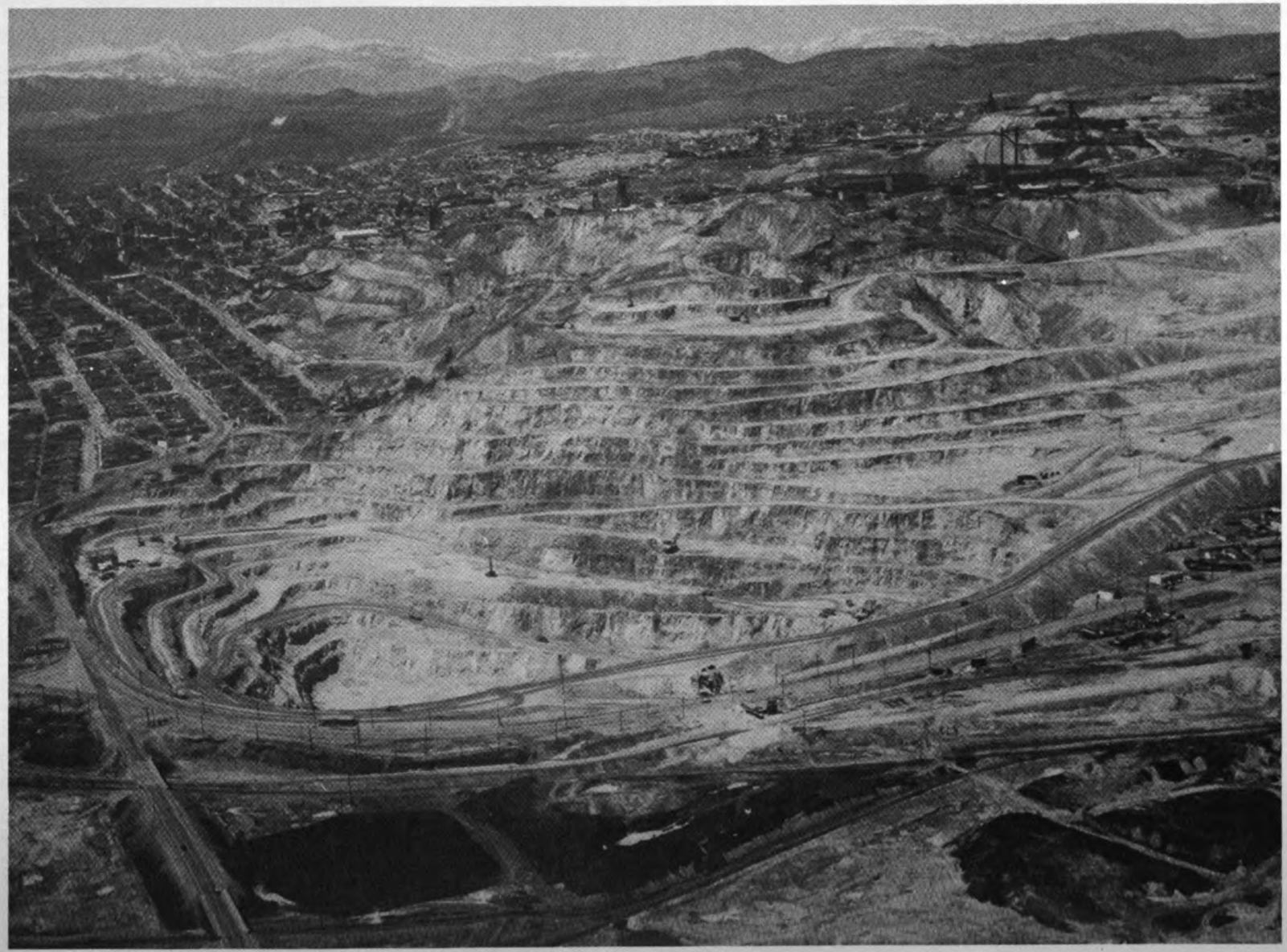

FIGURE 1. - Aerial View of Berkeley Pit and Vicinity. The view is to the west, with the city of Butte in the background and Butte Hill on the right.

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supplemented by surface test drilling, indicated an ore body of sufficient size and grade to warrant consideration as an open-pit mine. On this basis, a trial pit was excavated to explore the feasibility of mining the ore zone. The results were satisfactory in all respects, and a full-scale pit operation was authorized. At present, initial development of the pit, including removal of overburden and enlargement of the test pit to an operating size, has been completed, and the mine is in the early stages of its productive life.

Output increased from 14,000 tons of ore per day in 1956 (the first year of operation) to 17,500 tons per day by midsummer 1957. Daily production (April 1958) averaged 26,000 tons on a 5-day work-week basis.

ACKNOWLEDGMENTS

The author is indebted to the management and staff of The Anaconda Company for their cooperation and assistance in preparing this report, and to the officials of The Anaconda Company for permission to publish the material, photographs, and data contained herein. Special acknowledgments are extended to Chester H. Steele (vice-president in charge of western operations), E. I. Renouard (manager of mines), E. P. Shea (chief geologist, Montana Division), L. F. Bishop (research engineer), and particularly George W. Parker (pit superintendent) and John F. Dougherty (pit engineer), who gave freely of their time and assistance.

HISTORY

The Butte mining district came into existence in 1864 with discovery of placer gold near the present townsite. Soon gold-silver lodes were discovered and later, the copper deposits that were to give Butte world-wide fame as "the richest hill on earth." Until quite recently the bulk of Butte's production has come from narrow, high-grade veins mined through as many as 55 separate shafts, with more than 8,000 miles of underground workings. At present, 14 shafts are in normal operation hoisting ore, men, and supplies, and 30 more shafts are used for ventilation and service.

In 1947, after careful consideration of future domestic copper requirements and world market conditions, The Anaconda Company announced plans for the Greater Butte project, a program that promises to extend the life of the camp for many years. The keynote of the project is adaptation of large-scale mechanized-mining methods wherever possible to permit utilization of lower grade ore, particularly the low-grade "waste rock" bypassed by the vein mines of years ago. Mainstays of the Greater Butte project are the Kelley shaft, serving block-caving areas, and the Berkeley open-pit mine.

The Anaconda Company, formerly Anaconda Copper Mining Company, has been the principal land owner and mine operator in the Butte district since 1895. The company and its various subsidiaries form an integrated enterprise that includes the mining and smelting of copper, lead, zinc, aluminum, manganese, gold, and silver ores and the fabrication and distribution of metal products.

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PHYSICAL FEATURES

The Berkeley pit is on the southeast flank of Butte Hill between the unincorporated town of Meaderville and the city of Butte (fig. 2). To the west and northwest are the shafts and surface installations of the underground mines, and to the east is the broad valley of Silver Bow Creek and the Continental Divide.

The mean elevation of the area is over 1 mile, with altitudes ranging up to 8,000 feet on the Continental Divide. Precipitation ranging from 12 to 15 inches per year usually occurs as snow during the winter and spring months. Accumulative snow depths seldom exceed 2 feet. Temperatures range from 30° below to 90° above zero and average about 50°.

Butte is one of the leading mining centers in the West; and the Butte area, including Anaconda 26 miles to the west, is the population center of Montana. The city is served by two major highways, U. S. 10 and U. S. 91, and by four transcontinental railroads (the Chicago, Milwaukee, St. Paul & Pacific, Great Northern, Northern Pacific, and Union Pacific). A company-owned standard-gage railroad, the Butte, Anaconda and Pacific, provides rail transportation between the mines at Butte and the smelter at Anaconda.

GEOLOGY

A number of authoritative geologic studies of the Butte district are available (1, 2, 3).4/ The highly complex ore deposits are localized on the south margin of the Boulder batholith in an area of about 6 square miles.

Fractured quartz monzonite was altered and mineralized by ore-bearing solutions penetrating tension fractures. Subsequent faulting and repeated mineralization have created an extremely complex maze of veins and veinlets belonging to at least three systems. The oldest, largest, and most productive veins are in the east-west-trending Anaconda system; next in size, age, and productivity are the mineralized faults of the Northwest veins. The Steward or Northeast-fault veins intersect and displace veins of the two earlier systems and in turn are displaced by various postmineral dikes and faults. Although each system displaces its predecessor veins, all are nearly contemporaneous and are characterized by identical ores distributed in a concentric zoning pattern. In the central zone mineralization consists of copper sulfides oxidized and enriched to varying depths. In the intermediate and peripheral zones, copper mineralization gives way to zinc, manganese, and silver. The zonal arrangement is vertical as well as lateral but is masked and complicated by oxidation and supergene enrichment.

The mineralized quartz monzonite that constitutes the Berkeley ore zone is a portion of the central zone of mineralization created by the hydrothermal processes previously mentioned and enriched by downward percolation of surface waters. It includes not only the zone of secondary enrichment but remnants of

4/ Underlined numbers in parentheses refer to items in the bibliography at the end of this report. They are listed in the order of reference.

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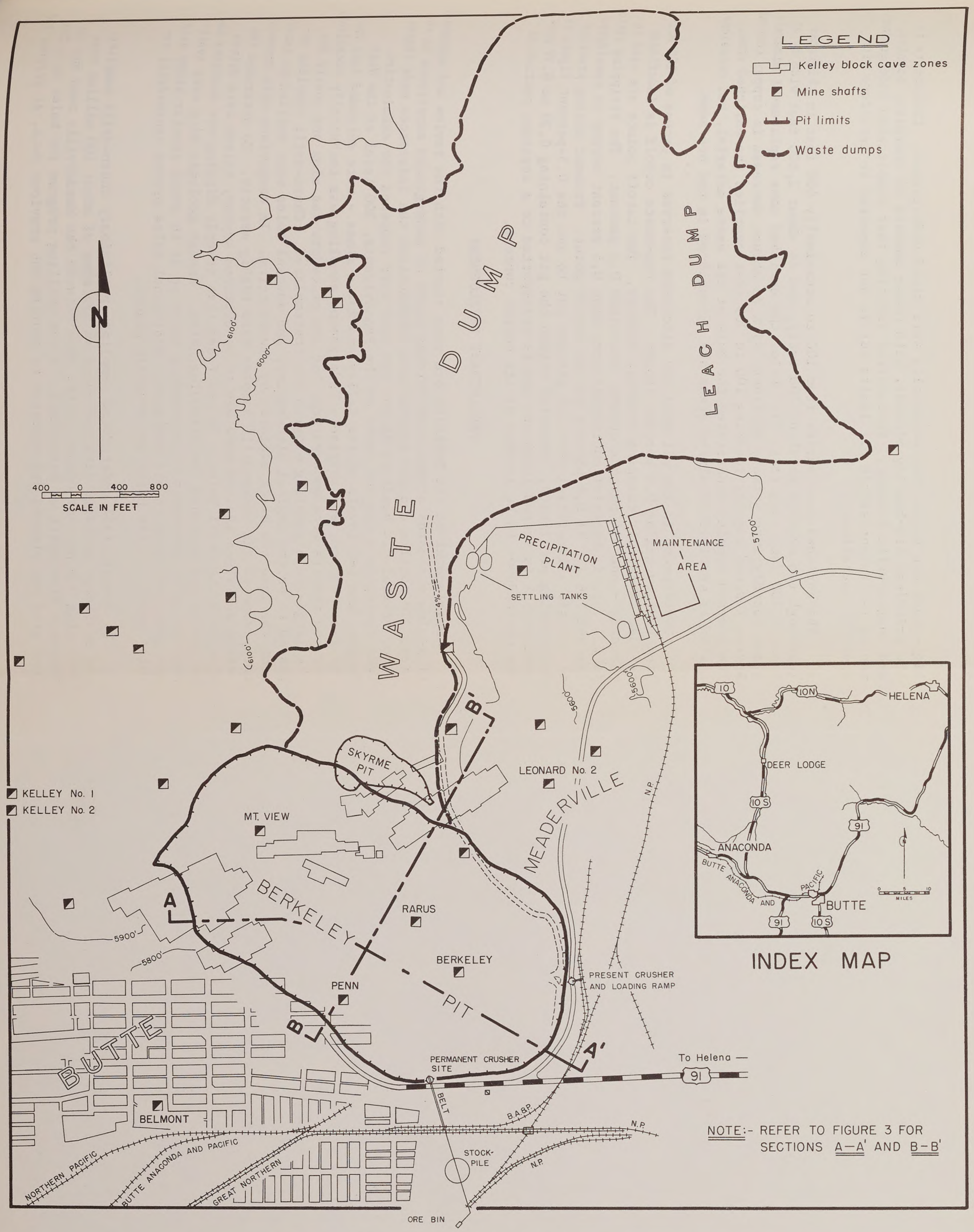

FIGURE 2. - Berkeley Pit, The Anaconda Company, Butte, Mont.

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high-grade ore veins that originally were mined underground. Chalcocite is the principal ore-bearing mineral, with lesser amounts of enargite, bornite, and chalcopyrite present. Postmineral faulting that complicated underground mining is present within pit limits but is not expected to interfere with open-pit operations.

The enriched zone varies from 100 to occasinally 600 feet in thickness (although the average is about 200 feet), and is about 2,600 feet wide by at least 4,700 feet long (fig. 3). Below the enriched zone replacement minerals grade rapidly into primary sulfides, with an abrupt decrease in copper content. Barren leached capping totaling 100 to 300 feet overlies the enriched zone. The leached capping constitutes the bulk of the waste material, but occasional barren or weakly mineralized areas are encountered in the ore zone.

Development in the pit area has disclosed reserves in excess of 100 million tons averaging 0.8 percent copper. The ore-waste cutoff is indefinite because of rapidly changing economic factors. Two cutoff points are used in planning - one 0.4 percent copper, the other 0.5 percent. The stripping ratio is 2.1 : 1, if material containing more than 0.5 percent copper is considered ore and 1.6 : 1 if 0.4 percent is the cutoff point. Present mining practice is to ship all material over 0.4 percent but to use the 0.5-percent figure in determining pit limits. Material within the pit containing 0.20 to 0.39 percent copper is termed leach ore and is transported to a separate section of the waste dumps to be leached of its copper content.

PRELIMINARY DEVELOPMENT

Development of the Berkeley ore zone started with the review and appraisal of geologic records accumulated through years of underground experience in the area. To confirm the old records and substantiate the inferences made therefrom, several old headings in the ore zone were reopened for examination. Four crosscuts - the 200 level of the Pennsylvania, 300 level of the West Colusa, and 600 levels of the Kelley and Rarus mines - were extended into the ore zone, mapped, and sampled. Underground sampling was technically excellent; and the results were encouraging, but the procedure was slow and costly for the large-scale sampling program now contemplated. Churn-drill sampling appeared to be the logical alternative, and several holes were drilled to intersect the same ore block explored by crosscutting. In comparison with crosscut data, some of the churn-drill samples were highly erratic. To determine the reason and since the ore zone was to be explored anyway, raises were driven alongside the drill holes. It was found that steeply dipping ore veinlets had deflected and enriched the offending holes. Enough geologic data were available to guide placement of succeeding holes so as to avoid similar steep veins and gobs remaining in old workings. Additional holes proved churn-drill results usable if the holes are properly placed.

By January 1954 underground sampling, preliminary churn-drill sampling, and available geologic data indicated an ore zone of about 100 million tons averaging 0.8 percent copper in the area between the Meaderville road and the Mountain View shaft on Butte Hill. A new drilling program for holes on a 200-foot grid was planned and executed to confirm the previous data. At present 138

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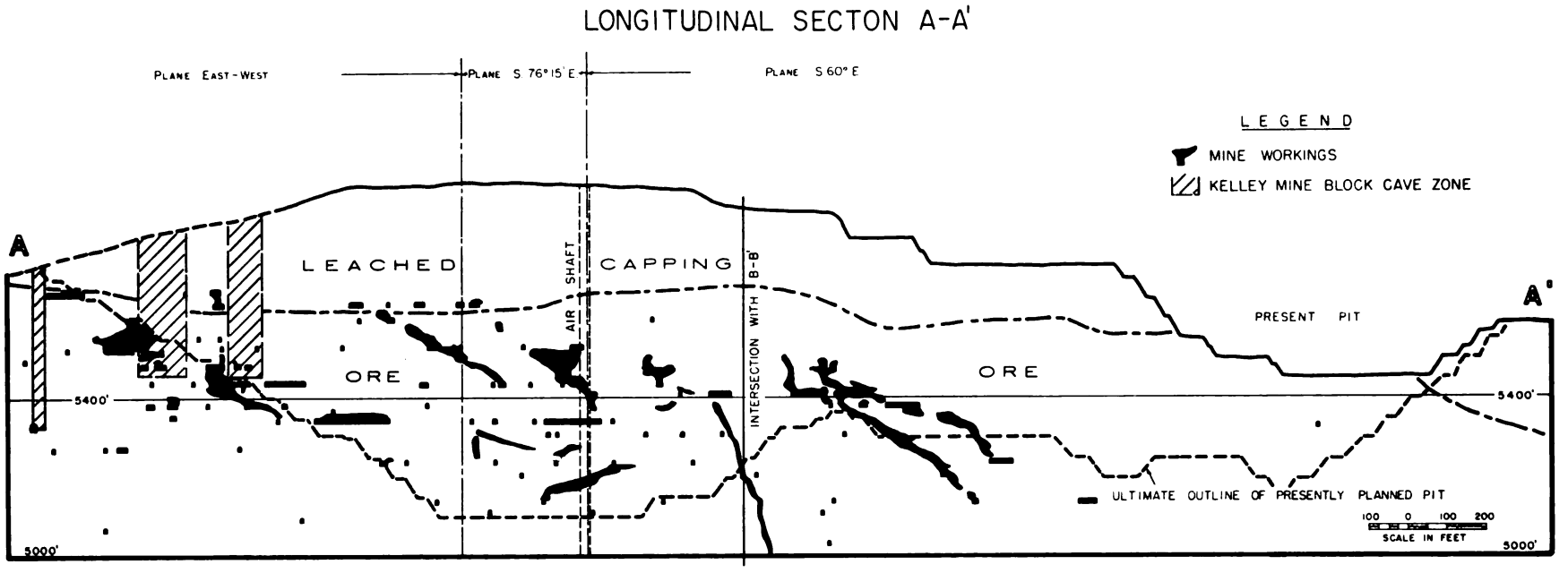

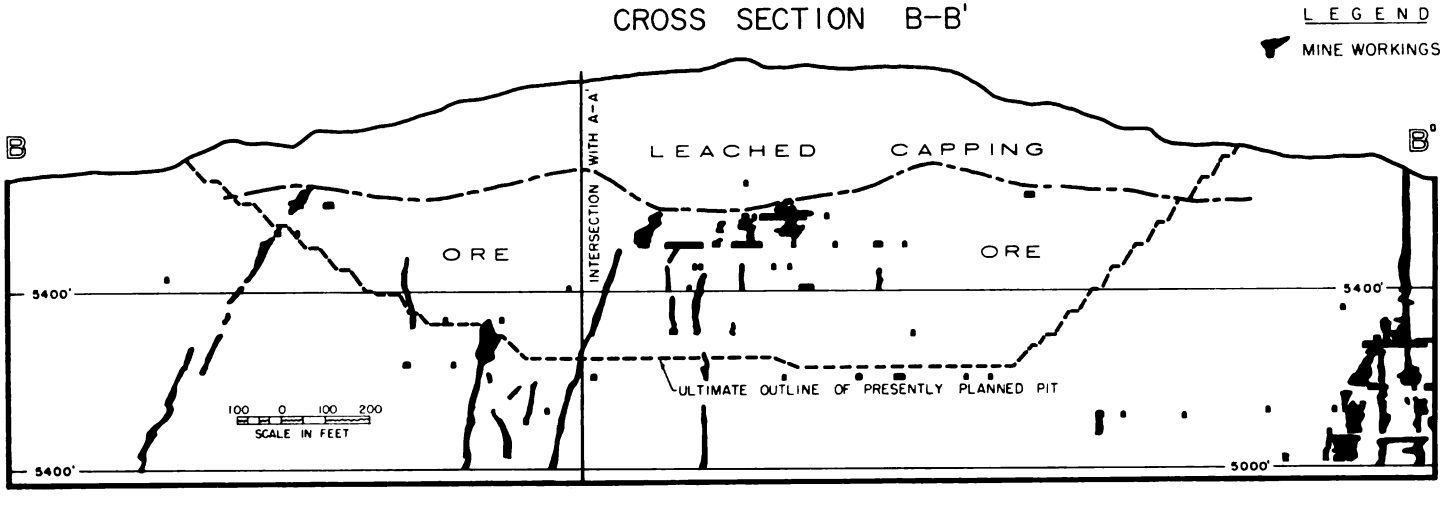

FIGURE 3. - Sections A-A' and B-B', Berkeley Pit.

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holes, totaling 80,556 feet, have been drilled west of the Meaderville road and north of the Butte-Helena highway.

EXPERIMENTAL PIT

In March 1955 excavation of a test pit was started (fig. 4). It was planned and so located that it could be expanded into the main pit should results prove satisfactory. The principal purpose of the pit was to serve as a final check on the basic data and computations that had gone into the planning of a major open-pit mine and to develop metallurgical processes for treating the ore. A secondary purpose was to confirm the feasibility of mining this pit with methods developed by experience in other Anaconda open-pit mines the world over, from the Skyrme and Alice pits on Butte Hill to the Cananea and Chuquicamata pits in Mexico and Chile.

Overburden to be stripped from the test pit ranged from 125 to 230 feet in thickness, and it was planned to extend the pit 100 feet vertically into the ore zone. On the basis of preliminary data, the top four benches were estimated to contain 597,966 tons of ore averaging 1.01 percent copper. Actual shipments from the same benches totaled 719,051 tons averaging 0.98 percent copper - close enough agreement so that the preliminary data could be considered reliable and that plans for a major pit could be made.

Ore shipments to the Anaconda smelter were treated separately to determine the most advantageous methods of processing the ore.

SAMPLING METHODS

Underground

As mentioned previously, four crosscuts from neighboring shafts were extended a total distance of 6,138 feet to explore the Berkeley ore zone at depth. Two of the four crosscuts were driven directly over each other to obtain a representative cross section of the ore body. The Pennsylvania 200-level crosscut was approximately 90 feet below the top of the ore body; the Rarus 600 crosscut (115 feet lower) was 90 feet above the bottom of the ore body. Bulk ore shipments from the development headings were considered to represent the true ore grade of the cross section. A total of 21,179 dry tons of material obtained from the crosscuts was sent to the Washoe custom sampling plant in Butte for analysis. This material averaged 0.83 percent copper, 0.22 ounce silver, and 0.002 ounce gold per ton.

Churn Drill

The Berkeley ore zone was developed by churn-drill holes placed on a 200-foot grid pattern. The Anaconda Company contracted the drilling to an independent company but provided a sampler to supervise the sampling procedure. Truck-mounted gasoline- and diesel-powered drills were used. The company provided access roads and supplied water to the drills by surface lines and tank trucks.

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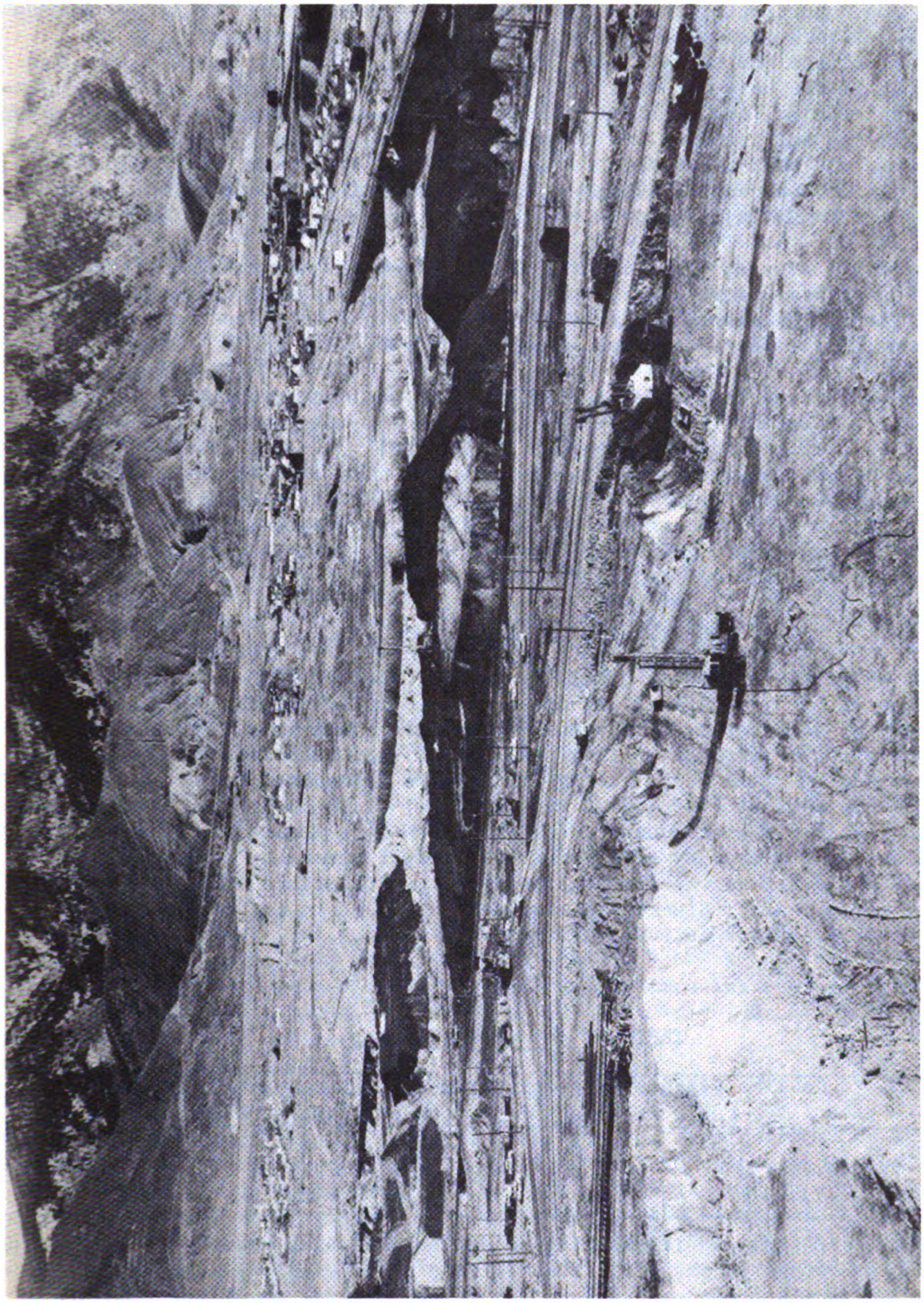

FIGURE 4. - Initial Excavation of Berkeley Pit, 1955.

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The upper portion of the hole was drilled with a 12-inch or larger bit to permit 10-3/4-inch casing to be installed through the leached capping and about 10 feet into the sulfide zone. The capping is barren, and sampling was deferred until the hole was within 25 feet of the sulfide zone. No casing was driven until the sulfide zone was entered unless necessitated by caving ground. Drilling in the sulfide zone was normally done with a 9-inch bit unless caving was encountered; then 8-5/8-inch casing was driven and the hole continued with a 7-inch bit. Water for drilling was lowered by bailer to the bottom of the hole to avoid contamination by material washed from the sides of the hole.

Sampling was by dart bailer at 5-foot intervals. Where metallurgical work was necessary, samples were split; one portion was sealed in glass for the metallurgical research department, and the second half was retained in a waxed carton and assayed for total copper, oxide copper, and silver.

Graphic logs on the scale of 1 inch to 10 feet were prepared as drilling progressed. Washed drill cuttings were cemented on heavy paper, and corresponding assays were posted as received. Each drill hole was studied individually. Assays of samples containing vein matter were reduced to 1.1 percent copper to discount the effect of encountering high-grade veinlets. Assays of disseminated ore were untouched. The average copper content of each 25-foot bench was computed from drill-hole data and used in reserve calculations and as a preliminary guide to pit design.

Computation of Tonnage and Grade

Churn-drill holes were plotted, and the area of influence was determined by the polygon method. Lines were drawn between holes and bisected; the sides of the polygon were formed by perpendicular lines drawn from the midpoint and closed by similar lines drawn from other midpoints. The area of the polygon was determined by planimeter. Assay values were determined by assigning to each block the average grade of 25 feet of hole, which in turn corresponds to the bench level. Thus the churn-drill samples may be considered as representing a column of ore made up of a number of 25-foot blocks or benches whose volume and grade are known. Tonnage and grade calculations were made individually for every bench. Electronic computors are used to reduce the huge volumes of calculations necessary in planning a pit.

Tonnage factors are summarized below:

TABLE 1. - Tonnage factors

	Leached capping, cubic feet per ton	Ore, cubic feet per ton	Subsidence material, cubic feet per ton
In place	12.0	11.5	20
Broken	19.2	18.4	20

There is no tonnage differentiation between shipping-grade ore, leach-grade ore, and waste in the pit. Leached capping, of course, is somewhat lighter. Surface subsidence or slump is broken material resulting from the the surface effect of block-caving activities in the Kelley mine.

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PIT PLANNING

Pit Design

Problems

The design of any mine, open-pit or underground, presents numerous problems. Some of the problems encountered in planning the Berkeley pit were unique in that the pit adjoins a metropolitan area. Space for waste disposal and service areas, such as the crusher and equipment maintenance yards, was at a premium. Pit limits were controlled as much by physical features as by geologic limits on ore grade and tonnage. The south boundary was set by U. S. Highway 91 and the Northern Pacific and Great Northern Railroad grades. The present easterly limit was established by the Meaderville road, railroad tracks, and Silver Bow Creek. To the northeast were the Leonard and East Colusa shafts, the former a producing deep mine and the latter an important unit in the underground ventilation system. To the northwest the original topography increases rapidly from a base elevation of about 5,600 feet to nearly 6,200 feet, and the pit size is again limited by producing mines. Privately owned homes and business buildings are within a few hundred feet of the pit limits on the southwest and northeast sides. Access roads to the pit, ore crusher, waste dump, and service area were planned to avoid heavy equipment moving across heavily traveled public roads. Another problem encountered was the occurrence, within the pit area, of subsidence areas resulting from block-caving activities in the Kelley mine. It was necessary to reduce the general pit slope in these areas from 45° to 38° to accommodate the disturbed ground, which in turn complicated bench and ramp design. Other more routine problems were the design of a pit outline based on geologic data but within the limits imposed by surface structures, ore grade and tonnage requirements, and ore : waste ratio. Pit ramps and roads must be placed economically for the shortest route to the disposal areas consistent with the optimum grade of road. Two crusher sites will be used during the life of the pit; road and ramp construction must be planned with the future site in mind.

Geological

The pit is first designed from a geologic standpoint; that is, pit outlines are established from geologic data without regard to the engineering problems of access, waste disposal, ramp development, etc. Certain established physical limitations are observed from the beginning, as shown in the previous section.

As mentioned previously, the deposit was thoroughly defined by drill holes set up on a 200-foot grid system. Samples from the drill holes were taken at 5-foot intervals and averaged over 25-foot sections to correspond to bench heights. These average assays are then plotted on cross-section maps corresponding to the north-south and east-west grid lines. In plan view the assay blocks appear as polygons; in section they are rectangles 25 feet thick and approximately 200 feet long. After the assay blocks are plotted on cross-section maps, the rough outline of the pit is sketched, bearing in mind that:

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1. Near the pit limits only rock above 0.5 percent copper is considered ore.

2. Ore blocks must support the removal of overlying waste.

3. Pit slope is to be 45°.

Within the pit rock containing 0.4 percent copper will be mined and treated, since it has to be removed anyway, but it is not now considered economic to expand the pit to include ore of less than 0.5 percent copper. The amount of waste that may be removed to mine a block of ore of a given grade is determined by an empirical formula. For example, the pit would not be expanded to include a block of 1-percent ore near the bottom of the pit overlain by 15 blocks of waste, but a block of 0.5- or 0.6-percent ore overlain by only one or two blocks of waste would be mined. Waste and ore removal must conform to the established 45° slope of the pit, so not only must the material directly above the block be considered, but also the material enclosed by a line extending at 45° from the block to the surface.

After a rough pit profile is completed for each cross section, benches are superimposed on the sketch. Minimum bench width is 50 feet toe to toe, including a protective berm of 21 feet. Bench slope is 60°; bench height was originally designed to be 50 feet, produced by the consolidation of two 25-foot working benches. In actual practice it was found to be more economical to have three 33-foot benches rather than four 25-foot benches per hundred feet of elevation. Bench width, slope, and height combine to produce the overall 45° slope of the pit (figs. 5 and 6).

Benches are transferred from the profile maps to the plan map by coordinates. Unwieldy pit contours on the plan map are adjusted by revising the estimated pit limits. Refinement of the pit design continues until a satisfactory compromise is reached between bench contours, grade of ore, and waste removal.

Engineering

After the basic pit outlines are determined, access roads and ramps for pit entry are developed to fit the design. Since the size and shape of the test ore body were known, the ramp was engineered to rise from the lowest bench in a counter clockwise pattern at plus 7 percent grade. The ramp reaches surface on the east side of the pit and continues at a modified grade not exceeding plus 4 percent as a haul road to the waste dumps, ore crusher, or service area without crossing public roads. Minimum ramp width is 40 feet, exclusive of a protective windrow of dirt on the pit side and bench berms on the bank side. Trucks from any working bench gain access to the haulroad at the intersection of bench and ramp. The pit is enlarged from the top down by pushbacks (figs. 5 and 6). After the top-level bench is retreated the desired distance, the ramp to the next lower level is pushed back, and so on to the bottom of the pit.

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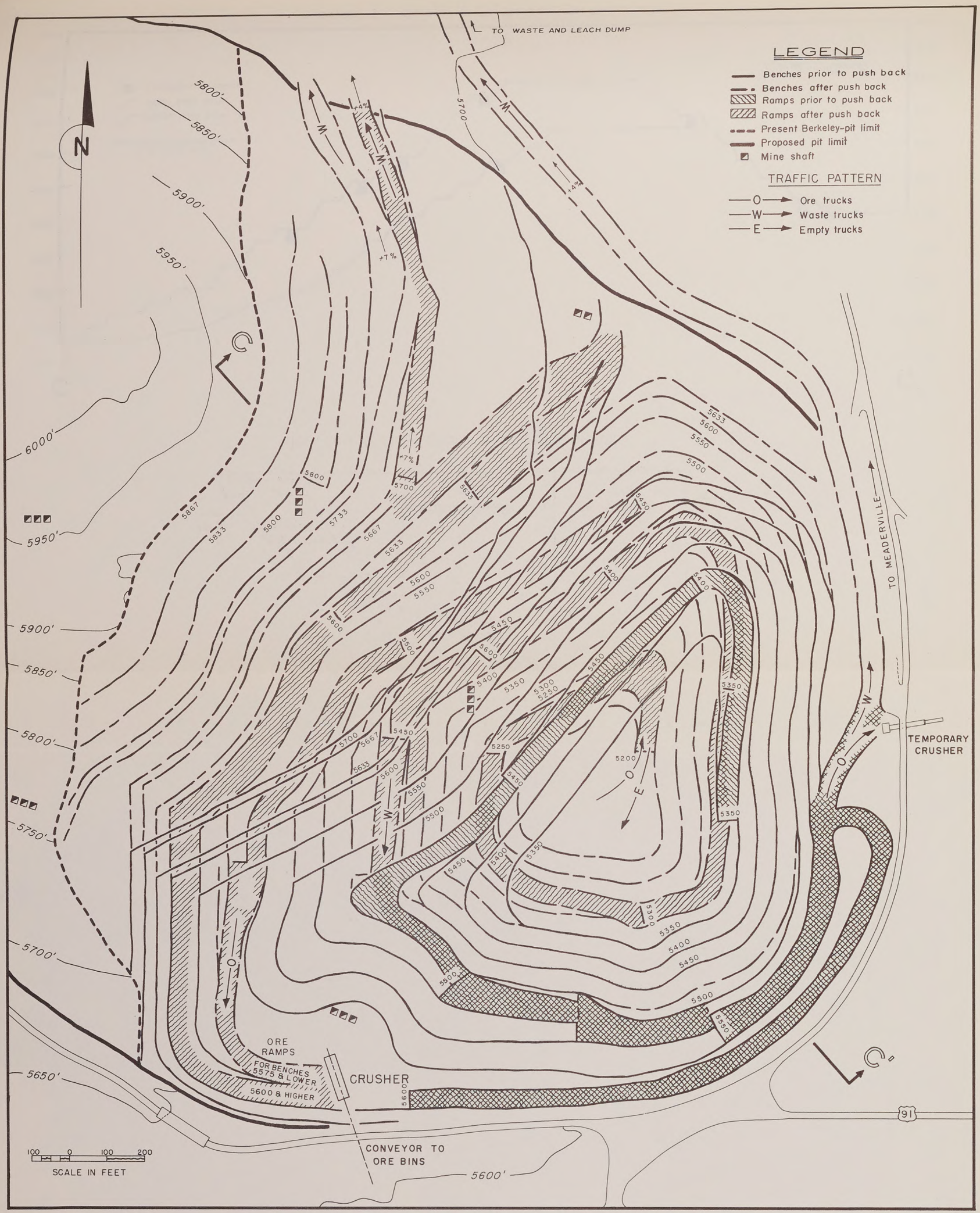

FIGURE 5. - Plan Illustrating Traffic Pattern and Push Back.

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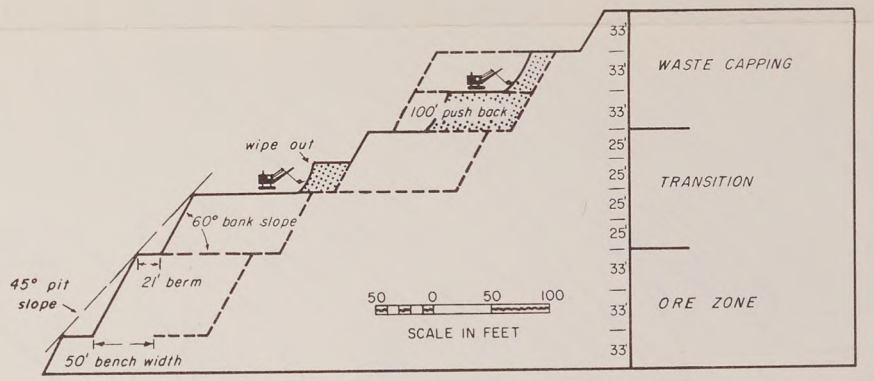

Idealized section showing pit development.

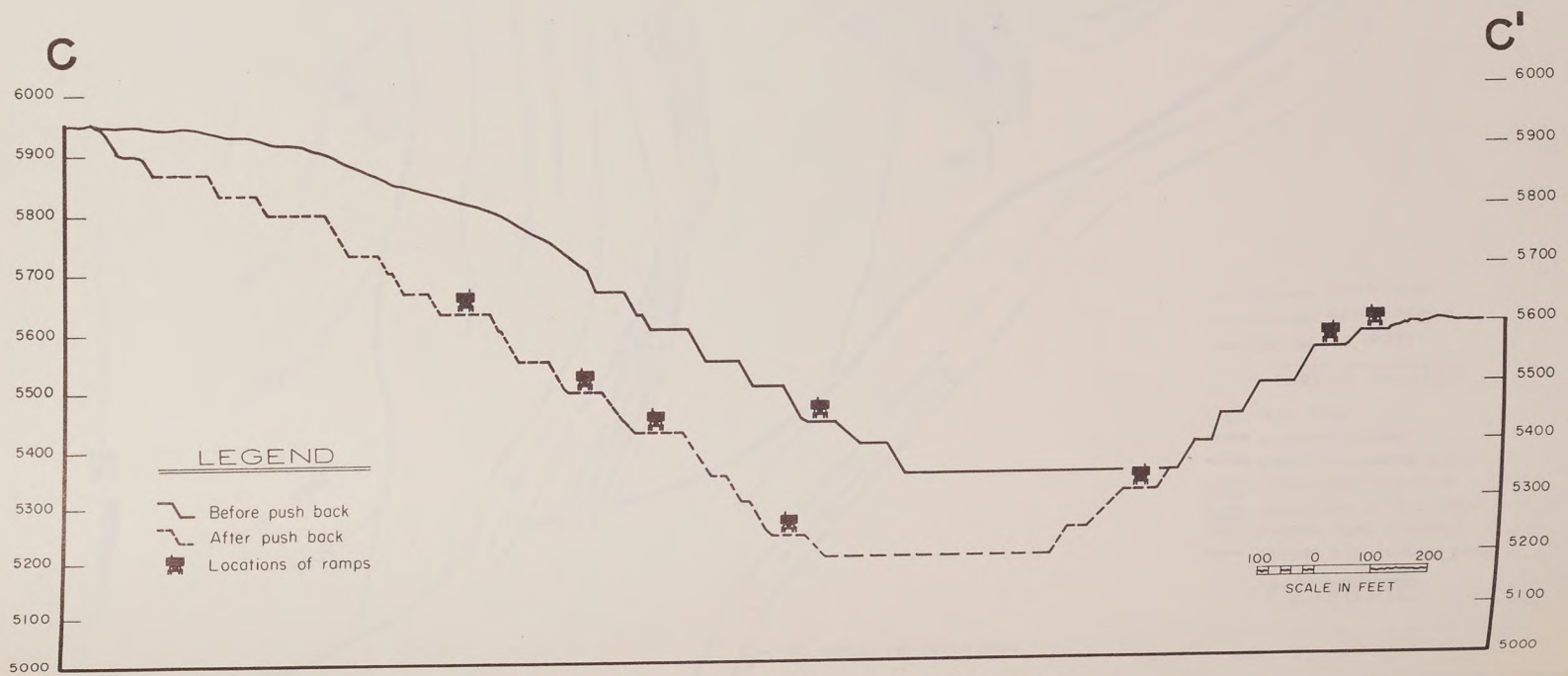

FIGURE 6. - Section C-C', Showing Pit Expansion.

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The major waste-disposal area is to be north of the pit in the valley of Silver Bow Creek, although several minor waste dumps are being utilized during development. The old East Colusa and Skyrme pits have been filled, and haul roads to the permanent dump sites have been developed on waste fill. Several active dump sites are continually maintained to avoid traffic congestion.

Leach-grade ore is handled in a manner similar to waste. At present all leach-grade ore is segregated in one portion of the permanent waste-dump area for leach treatment. When this space is exhausted, a new leach dump will be developed on the extreme north-east side of the permanent waste dump. The leach process consists simply of wetting the dump with an ordinary sprinkling system and collecting the pregnant water after it has percolated through the pile; the copper-bearing water is piped to the precipitating plant, where it is added to the 35,000 tons of water pumped daily from the deep mines and the copper is extracted from solution by replacement with iron.

Engineering Control

Close engineering control of all mining activity is necessary to develop the pit according to plan and to maintain ore production at the desired grade and tonnage level. Ore volume and grade are forecast and checked daily, bench elevations and ramp development are closely watched, and bench expansions are projected and controlled.

Bench elevations, ramp grades, and ore and waste volumes are controlled from semipermanent triangulation stations and temporary bench marks established in the pit by transit. Bench levels are maintained by the device shown in figure 7. It is simply a crosshair-equipped, shopmade leveling tube that is established by transit at a station from which the working shovel will be visible for several days. A sampler or oiler can, by sighting a target on the shovel, assist the shovel operator in keeping the bench on grade. Operating control, especially of ore volume, is maintained by plane table with an occasional check by transit and is checked against daily truck tally. Waste volume is computed monthly or more often if necessary. Working schedules for the shovels are based on known ore-production requirements plus waste removal for future development. Working places in ore are established daily and identified by red and green flags on alternating days.

Grade Control

Grade is controlled by selective mining and blending of ore from several faces. Grade of ore, determined originally by prospect drilling, is checked on each bench by blasthole sampling, which is used for all production planning. Increasingly better control will be possible as the number of working faces increases. An average grade of 0.8 percent copper is required for most economical recovery of metal in the processing method developed by The Anaconda Reduction Works. The following comparison shows the tons of ore and grade computed from churn-drill samples, blasthole samples, and smelter returns:

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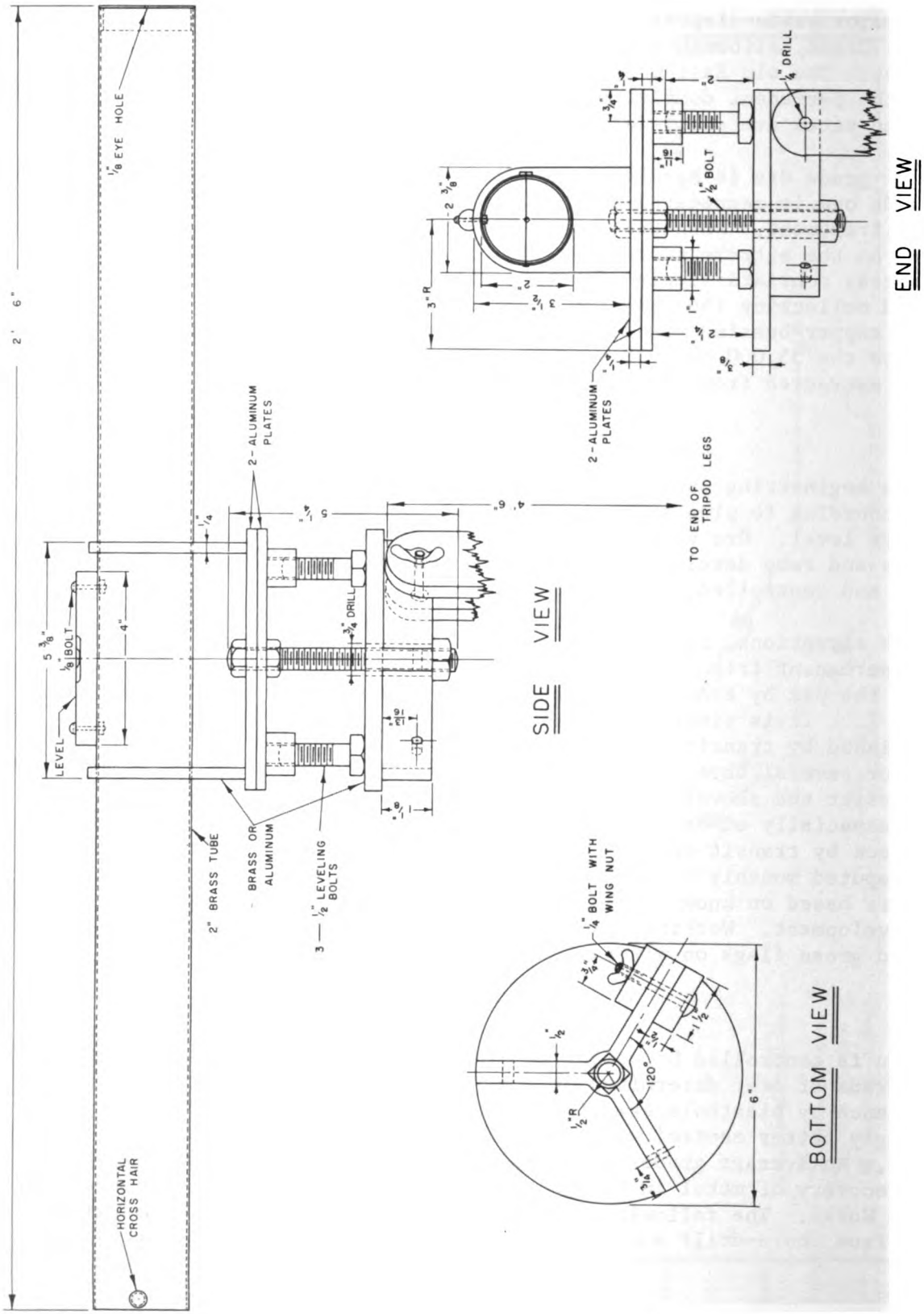

FIGURE 7. - Bench Leveling Device.

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TABLE 2. - Tons of ore and grade

	By churn-drill samples		By blasthole samples		By smelter returns	
	Tons	Cu, percent	Tons	Cu, percent	Tons	Cu, percent
Bench 5450	155,267	0.96	176,031	0.97		
Bench 5475	328,448	1.00	361,326	.98		
Bench 5525	170,413	.78	145,933	.83	127,416	0.78

Forecast Planning

Production forecasts are made on a daily, monthly, semiannual, annual, and long-term basis. The daily and monthly forecasts are more or less defined by production quotas. Longer term forecasts are based on a growth factor, since the pit is just emerging from development and will continue to expand for several years. The original test pit and a great deal of the initial stripping were contracted to an independent company, thus relieving The Anaconda Company of the responsibility of acquiring and maintaining heavy equipment and manpower until the pit was actually in production. Therefore, in addition to production planning, long-range forecasts must consider the interrelated problems of orderly pit development and equipment procurement.

PIT OPERATION

Organization

The table of organization shown in figure 8 is self-explanatory. All of Anaconda's mining activities in the Butte area are directed by the resident manager of mines, with the assistance of the engineering, mining-research, geology, and other departments. Direct supervision of the pit is the responsibility of the pit superintendent, assisted by the pit engineer, who is responsible for engineering and planning, and the pit foreman, who is in charge of actual mining operations. The pit foreman is assisted by a staff of operating foremen in charge of transportation, drilling and blasting, crushing, equipment maintenance, etc. Engineering, geologic, research, sampling and assaying, and related services are obtained from departments of the company concerned with those activities.

The Anaconda Company contracted excavation of the initial test pit, and later its enlargement to a producing mine, to an independent contractor, with the understanding that, when the pit achieved full production status, operation would revert to the company.

Actual transfer of control occurred smoothly and with a minimum of confusion through close cooperation between the company and contractor. For some time before formal transfer of responsibility the contractor was gradually replacing units of his own equipment with leased company-owned and operated equipment. Thus when the contractor withdrew, the company assumed control of a fully equipped, operating mine.

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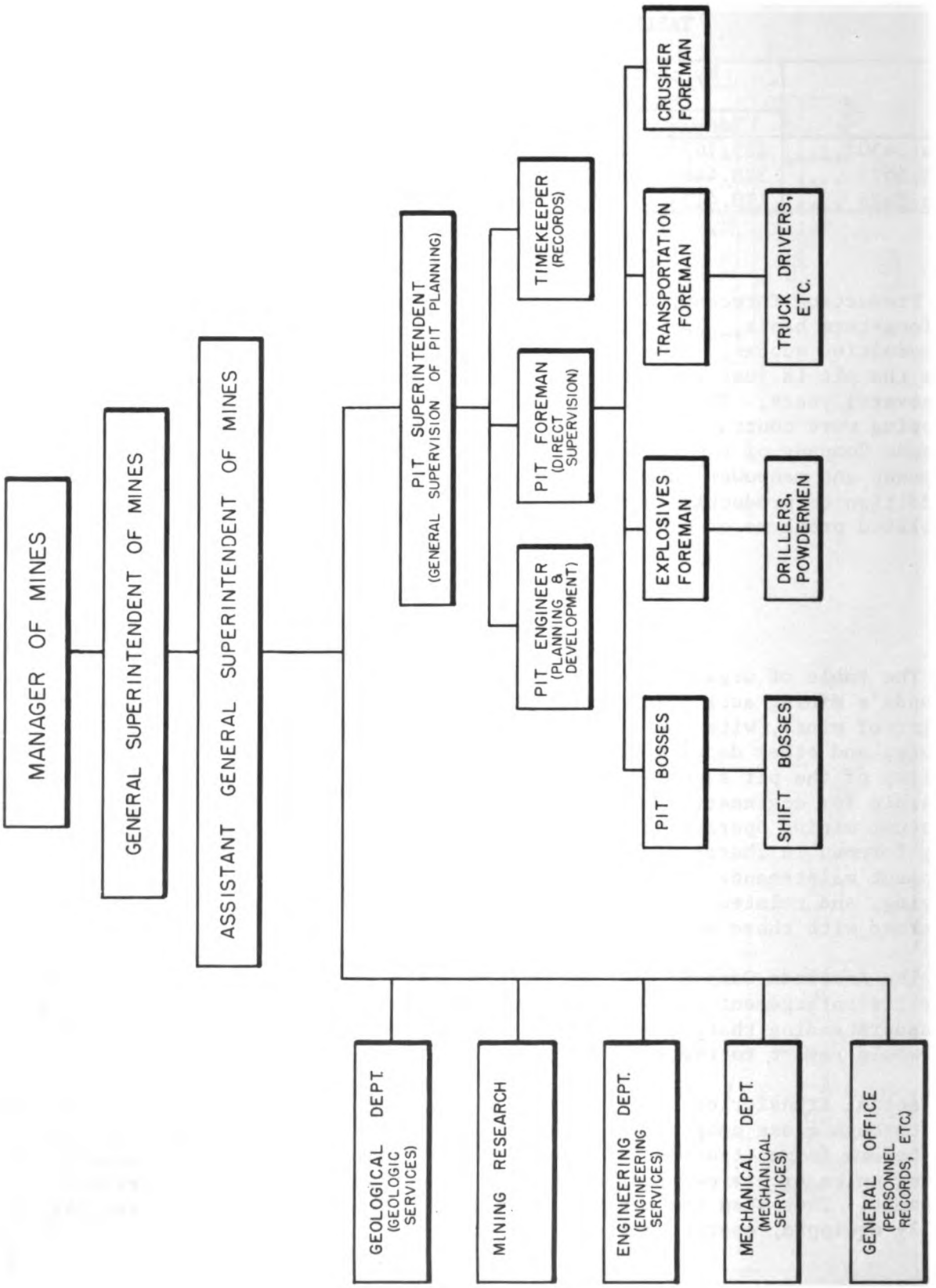

FIGURE 8. - Organization Chart, Berkeley Pit.

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Development

The Berkeley pit has passed the purely development stage where production is of secondary importance and is well into the next phase, where the converse is true. Pit development is a continuing function existing as long as overburden remains and until the pit reaches its final size. Mining and development overlap or occur simultaneously and are difficult to distinguish. Operating cycles, whether concerned with ore or waste removal or ramp development, are similar and are treated together under the various headings.

Stripping

The ore zone is overlain by 125 to 300 feet of barren, leached overburden that must be removed before mining. One major problem in stripping is removal of surface structures. A number of shafts and headframes, both active and inactive, are in the pit area. Several shafts are part of the underground ventilation system and must be preserved as long as possible. This is done by cribbing and temporarily sealing the shaft while stripping and, later, mining are in progress in the immediate area. Steel frame structures, such as headframes, drys, and other mine plant buildings, are dismantled; wooden structures are salvaged if time and value warrant or are demolished. Powerlines and other vital surface structures are relocated when necessary. Air lines from the central compressor and pipelines from the deep mine pump station were relocated and protected by burial in a culvert beneath the waste dump.

Mining Plan

Mining is by electric-powered shovels and truck from benches 100 or more feet wide and 33 feet high. At present 19 benches are in use, and this number will be increased to 34 as the pit becomes fully developed. The pit was originally designed to have 33-foot benches in waste and 25-foot benches in ore to provide for greater selectivity in mining. The selectivity was found to be generally unnecessary; and all benches, except those in the transition zone between capping and ore, were converted to 33 feet to take advantage of economies in drilling, blasting, and loading. On reaching the final pit limits, the benches will be consolidated 2 : 1 to form 67-foot benches. A 50-foot berm will be preserved on alternate benches for safety and reentry. Bench slopes stand at 60°, but the final pit slope, including berms, will be 45° in hard rock and 38° in broken material.

Pit access is by a counterclockwise spiral ramp now 0.7 mile long at a grade of 7 percent from pit bottom to the rim (fig. 9). The portion of the pit that includes the hillside above the valley floor is serviced by feeder ramps. Waste and leach ore are carried by truck over haul roads not exceeding 4-percent grade. Crushed ore is transported by belt conveyor to trackside storage for later shipment by rail to the Anaconda smelter.

Blasthole Drilling

Both ore and waste require blasting. Two types of drills are used, three Bucyrus-Erie crawler-mounted 40-R electric rotary drills (fig. 10) and a

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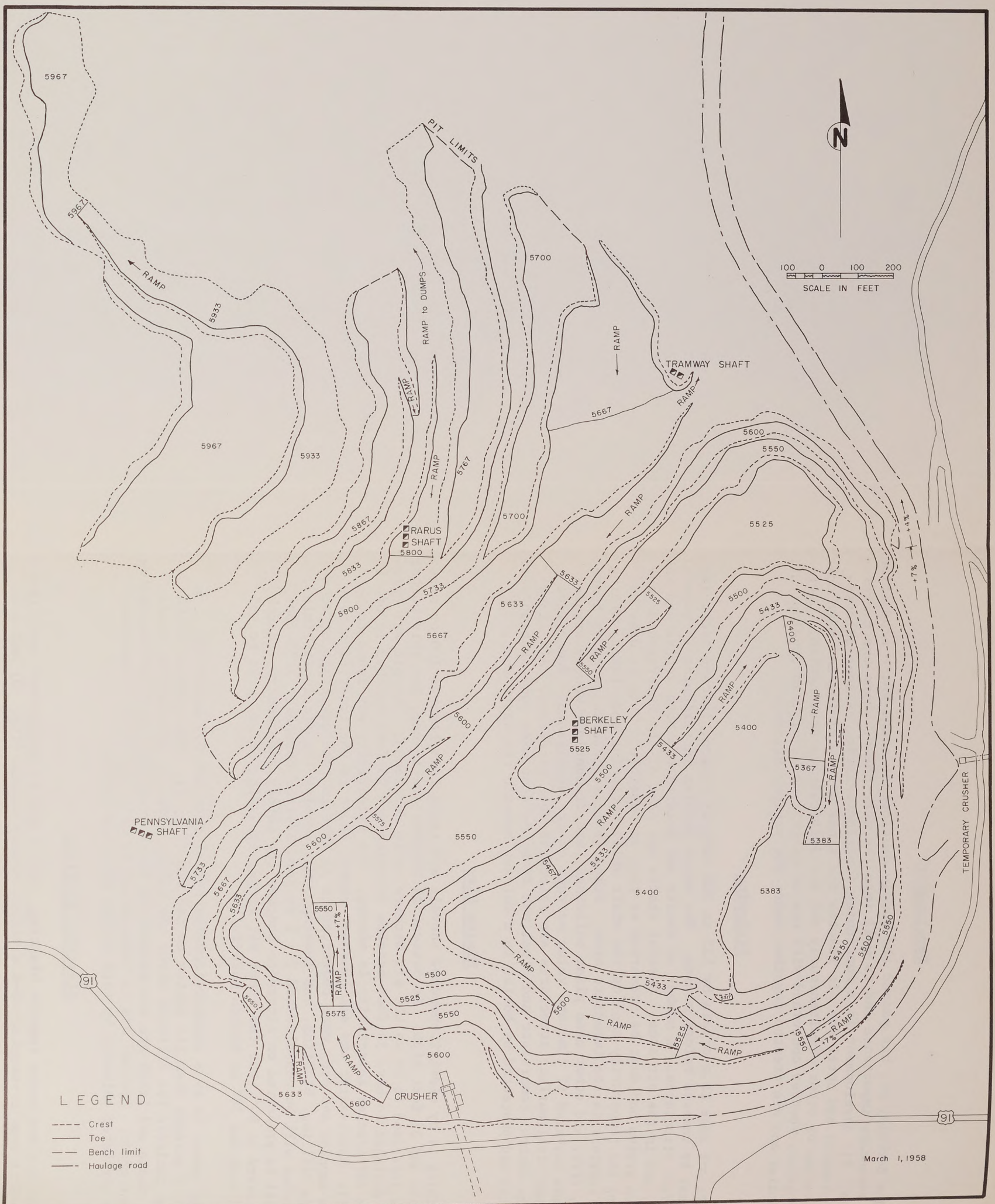

FIGURE 9. - Plan of Berkeley Pit.

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highly mobile Joy 225-AST diesel rotary drill mounted on a T-800 Ford truck (fig. 11). Both drills are used interchangeably in ore and waste; the smaller is employed principally in areas remote from electric cable leads or where special holes are needed quickly.

Time studies of the blasthole drills give the following information:

TABLE 3. - Typical drill performance[1/]

	Track-mounted drill[2/]	Truck-mounted drill[3/]
Setup	8.75	18.75
Drilling	60.0	48.0
Moving	18.0	23.0
Adding steel	4.0	
Lubrication	1.0	1.0
Delays	8.25	9.25
	100.00	100.00

1/ Percentage of available shift hours.
2/ Based on 16 holes of 42.5 feet.
3/ Based on 18 holes of 38 feet.

TABLE 4. - Comparative drilling rate

Machine	Material	Average time, min.		Drilling rate, in./min.	Moving time, min.
		45-foot hole	32-foot hole		
40-R-No. 1	Waste	25.5		21.2	2.75
40-R-No. 2	do.	23.5		22.9	2.00
225-AST	Ore		10.1	38.0	.4

The larger drill uses a 9-inch air-cooled tricone type bit, the smaller drill uses a 6-1/4-inch bit of the same type. All bits are used to failure; as yet there has been no attempt to recondition used bits, although such action is being considered. Bit failure is generally caused by bearing failure resulting from excessive wear on the bit shoulder. The bits, being air-cooled and air-lubricated, are especially vulnerable to abrasion in damp ground, where air is less effective. Bit-performance statistics are shown in table 5.

TABLE 5. - Bit performance

	Truck-mounted drill[1/]	Track-mounted drill[2/]
Bit type	Hard formation	Hard formation
Size	6-1/4 inches	9 inches
Average life (feet):		
Hard rock	1,472	3,725
Soft rock	2,422	6,240
Overall	2,098	4,826
Average feet per shift:		
Hard rock	540	540
Soft rock	670	617

1/ Based on a study of 26 bits. 2/ Based on a study of 41 bits.

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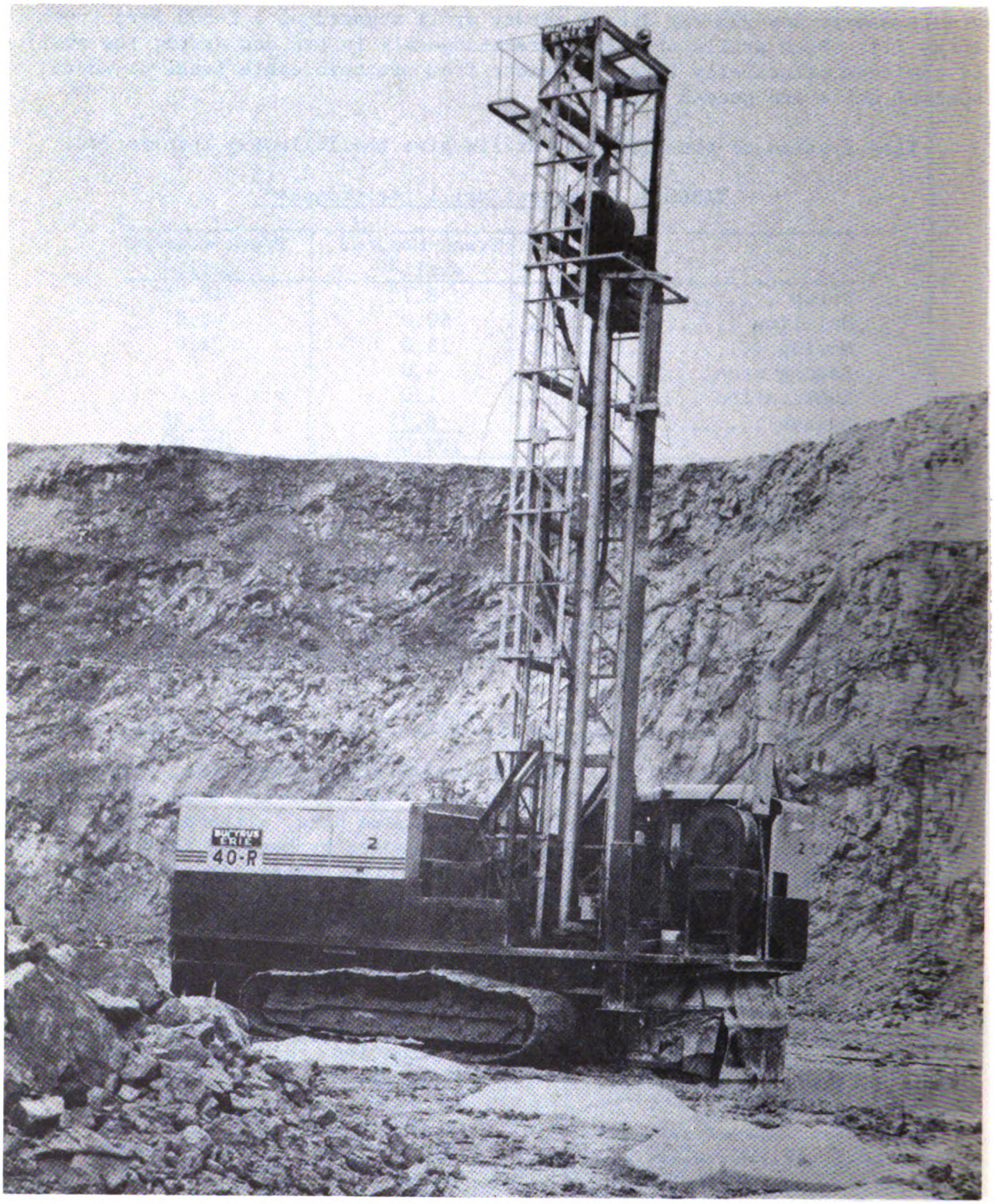

FIGURE 10. - Track-Mounted, 9-Inch Rotary Drill. Note ejected cuttings used for stemming.

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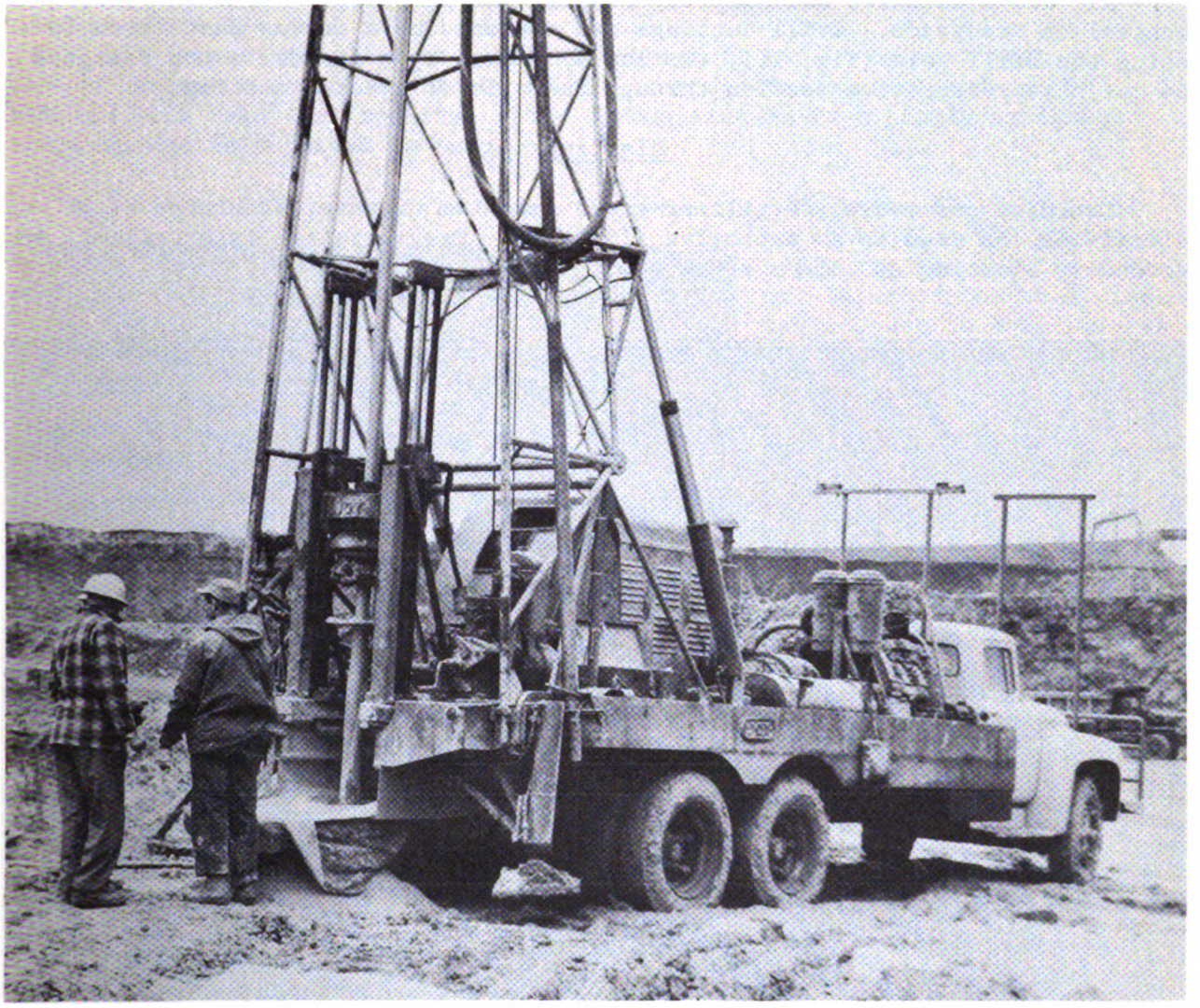

FIGURE 11. - Truck-Mounted, 6¼-Inch Rotary Drill. Note dust apron to collect cuttings for sampling and stemming.

Waste blastholes are drilled at intervals of 20 to 23 or more feet in a single row of seven holes to a depth of 40 feet, about 7 feet below grade. Cuttings are ejected by air pressure and captured and retained at the collar for use as stemming. Burden on waste holes is about 10 feet at bench level and 25 feet at the toe.

At present no more than seven waste holes are detonated at one time to minimize vibration. Should there be a delay between drilling and blasting, a second series of six holes will be drilled, leaving a space or breaker between groups to be drilled after the first series is blasted.

Blastholes on ore benches are drilled on 20- to 23-foot centers in a single row of up to 16 holes. Ore holes are drilled 5 feet below grade to a depth of 38 feet. Burden is 12 feet on the bench crest and 27 feet at the toe.

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All ore blastholes are sampled, mapped, and plotted to maintain running control on ore grade. Drill cuttings are captured by a canvas dust apron covering the drill hole (fig. 11); samples are taken by a slender scoop designed to cut a representative section through the pile of ejected cuttings.

Blasting

Ordinary commercial fertilizer-grade ammonium nitrate, saturated with diesel oil, is used as an explosive (fig. 12). Fragmentation is excellent, and secondary blasting is seldom required.

FIGURE 12. - Ammonium Nitrate Used As an Explosive.

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The nitrate, purchased in 50- and 80-pound bags, is carbonized by addition of about 3/4 to 1 gallon of diesel oil to each bag. Prilled nitrate[5/] (fig. 13) is preferred for the ease with which it can be treated with oil. Before treatment ammonium nitrate is not considered explosive and can be handled with relative impunity; after carbonizing it is a highly explosive compound and is regarded as such.

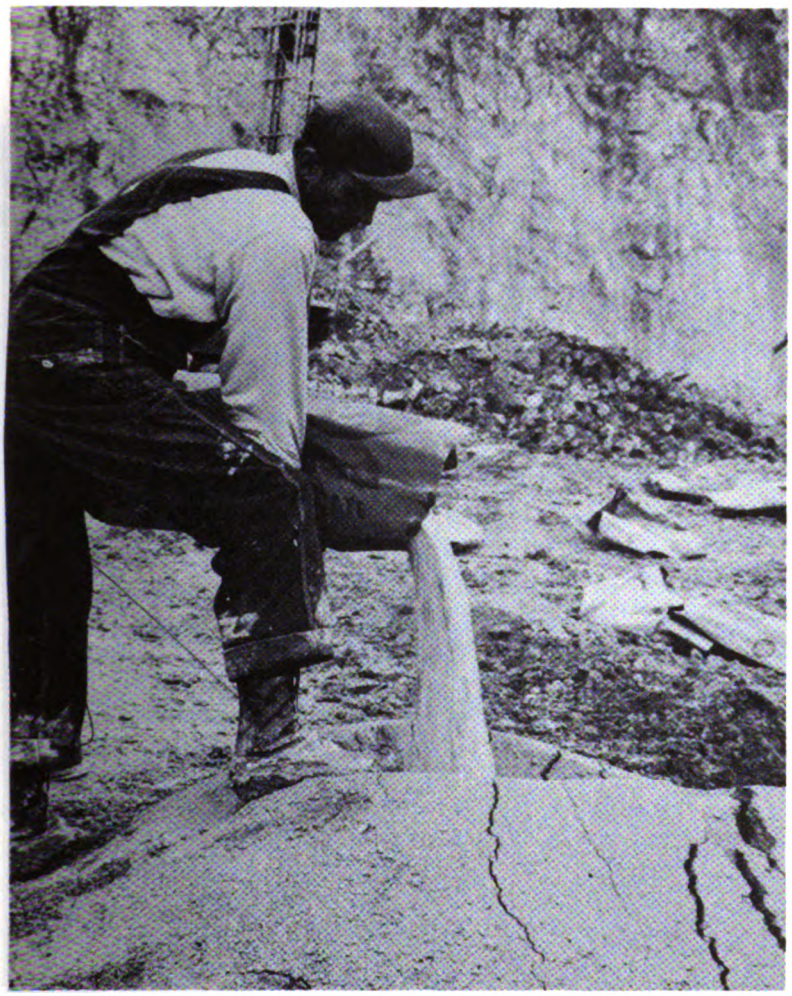

FIGURE 13. - Loading Rotary-Drilled Blastholes With Prilled Ammonium Nitrate.

Large (9-inch) drill holes require 450 pounds of explosive per hole in waste; ore holes of the same diameter but not so deep require 400 pounds. The smaller 6-inch holes use 150 pounds of nitrate in both ore and waste. When loading is complete, the hole is stemmed to the collar. The average time consumed by a five-man crew in loading a hole is 3.9 minutes. Holes are primed with a 5-1/2-pound can of nitramite or with one XC-49P puck, a high-explosive detonator named from its resemblance to a hockey puck. Occasionally, where it is desirable to increase the impact of the explosive, the normal speed of detonation is increased from 10,000 to 13,000 f.p.s. by priming with a 10-pound cylinder of 60-percent gelatin dynamite.

Primers were formerly sensitized with millisecond-delay caps and detonated by electricity, but now Primacord is used exclusively. The change was prompted by the danger of premature blasts that might be caused by stray electric currents from drills and shovels, from lightning, or from the mobile radio transmitters used in communication.

Nearly 6 tons of ammonium nitrate, at a cost of about $80.00 per ton, is used daily to produce a factor of 6.37 tons of ore per pound of powder.

5/ A commercial form in which the nitrate grains are nodulized in the size and shape of No. 6 shot.

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Secondary blasting because of unbroken rock has been unnecessary; however, during the winter large frost slabs occasionally form. Most of them can be broken by the shovel, but the remaining few that are too large to enter the crusher are broken by mudcapping with a single stick of high-strength gelatin dynamite.

Loading

Six crawler-mounted shovels are now in service. Five are Bucyrus-Erie 150-B's, with 6-yard buckets (fig. 14); one is a Bucyrus-Erie 71-B with 3-yard

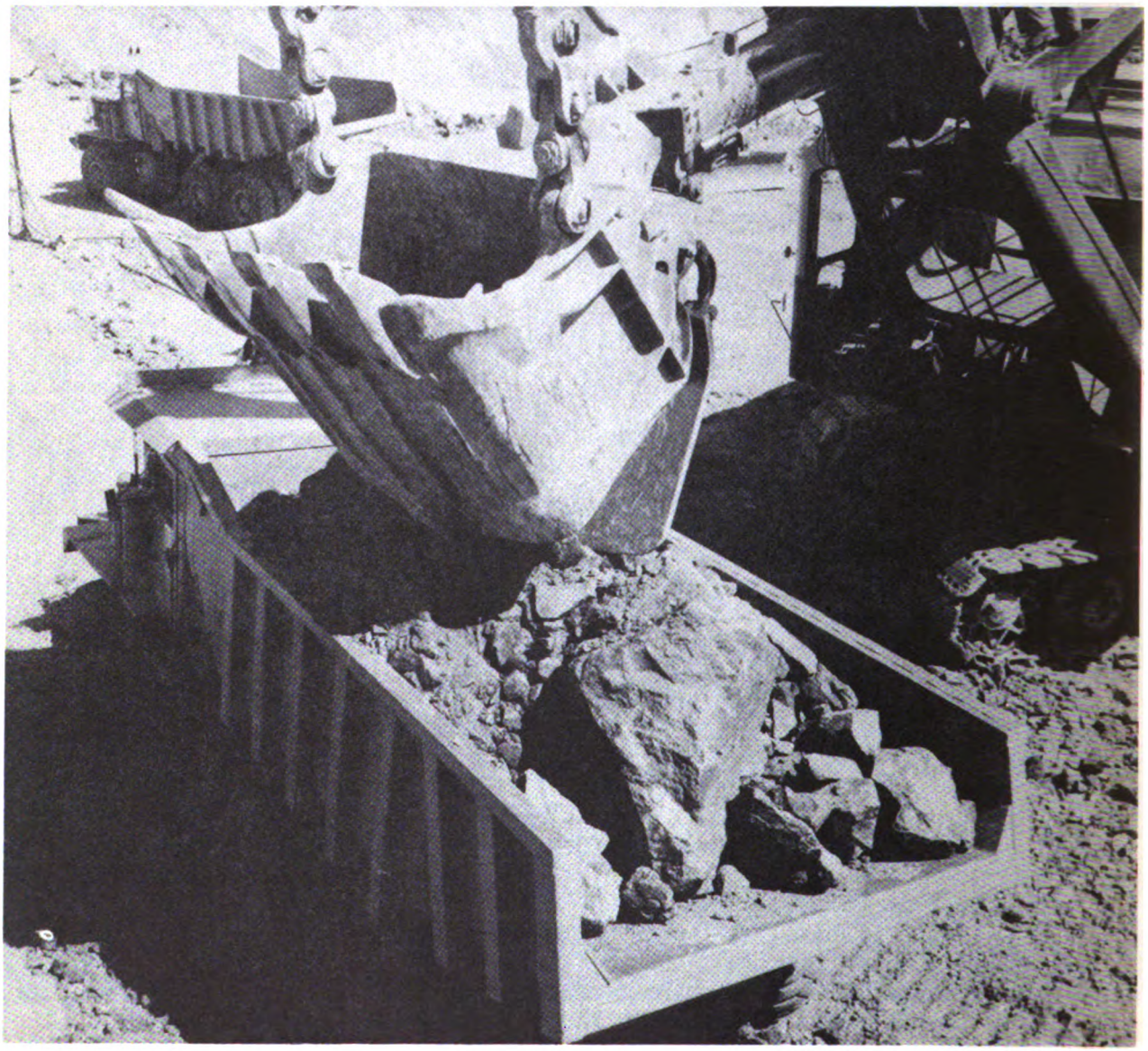

FIGURE 14. - Loading 34-Ton Truck With a 6-Yard Shovel.
(Courtesy, The Anaconda Company)

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capacity. The large shovels are on straight production work in ore or waste; the smaller shovel is kept as a spare and used whenever needed as a substitute for a larger shovel or for cleanup work on roads and ramps.

Shovel crews consist of two men, an operator and an oiler. Electric power is conducted to the shovels at 2,300 volts by heavy, three-conductor safety cable. The cable lies on the ground, except where it crosses roadways and is supported by movable towers to avoid abuse from heavy traffic.

Based on past performance the 150-B's can load 8,718 tons and the 71-B 4,864 tons per 8-hour shift. Average loading time per truck is 2.51 minutes. Allowing for routine maintenance and an occasional breakdown, shovels are considered 84 percent available.

Trucks are loaded from alternate sides of the shovel thus there is no loss of shovel time in positioning trucks; as one is being loaded the next is already moving into position (fig. 15). Also, there is no loss of shovel time in making unnecessarily long shovel swings.

Transportation

At present 43 trucks are in use at 80- to 85-percent availability. Eighteen are 24-yard end-dump Mack trucks with a rated capacity of 34 tons, and the remaining 25 are Model 4-FFD 34-ton Euclid trucks. All are torque-convertor equipped, rear-dump, diesel-powered models with dual drive and dual rear axle. Interesting modifications are engine exhausts in the dump bed to minimize load freezing in cold weather and bars between the rear dual wheels to prevent rocks from wedging between tires.

The average waste haul is 2.0 miles from the pit floor and 0.8 mile from the top of the pit to waste and leach dumps. The average ore haulage distance is 0.58 to 0.62 mile to the present crusher site. The average truck speed is 13.7 miles per hour. The results of a time study of truck performance for 1 month are shown in table 6.

TABLE 6. - Typical truck performance

Truck capacity ..... tons	36
Average haul ..... miles (one way)	1.30
Speed ..... minutes per mile	4.38
Loading time ..... minutes	2.51
Travel time ..... do.	11.39
Dump time ..... do.	.84
Elapsed time ..... minutes per trip	15.04
Trips per shift	31
Ore hauled per shift ..... tons	1,116
Average cost per ton-mile	$0.0892

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FIGURE 15. - Trucks Positioned on Opposite Sides of Shovel.
(Courtesy, The Anaconda Company)

Pit Maintenance

Ten bulldozers are in use in the pit. One D-6 Caterpillar is assigned to each large shovel to keep the loading area free of rock and keep the broken rock piled up for easier shoveling. Another D-6 is assigned to the smaller shovel for the same purpose. Occasionally the 71-B shovel is used to clean up rock on the roads and ramp. One D-8 Caterpillar is assigned permanently to keep the waste dump smooth and on grade. Another D-8 is available for general utility work, preparing surfaces for stripping or drilling, initial bench or ramp construction, and heavy ramp and bench maintenance. A motor patrol grader and sprinkler truck are used to maintain the road surfaces in a smooth, trouble-free condition for maximum tire life. Roadways were experimentally treated with calcium chloride, lignin sulfonate, and other dust-allaying agents. The results were not considered advantageous enough to warrant

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continuing treatments with commercial preparations, although waste oil from the garage will be used when available.

Equipment Maintenance

All units of equipment are on regular maintenance schedules. Relatively immobile track-mounted equipment, such as shovels, drills, and tractors, is fueled and serviced on the job during lunch periods and shift changes by a 4,000-gallon tank truck and a mobile lubrication truck. Mobile units are serviced periodically in the garage. All units receive a mechanical checkup and thorough lubrication after 100 hours of operation, a minor overhaul after 500 hours, and a major overhaul after 15,000 hours. For automotive equipment this corresponds to service at 1,000, 5,000, and 150,000 miles and includes the appropriate services, tuneup, minor repair and adjustment, and repair or replacement of major units, such as engines, converters, transmission, etc.

On-the-job breakdowns are cared for by a repair truck that includes in its equipment an electric welder for on-site welding, an air-compressor to power a complete set of air tools, and a monorail crane for removing or replacing motors, gear boxes and other heavy items.

Except for some on-the-job lubrication and minor repair, all automotive and mechanical equipment is serviced in the large, modern, well-equipped garage capable of handling major repairs as well as routine maintenance.

The garage, housed in a steel frame structure 90 by 360 feet (fig. 16), is designed for maximum utility. More than half the floor area, running lengthwise of the building, is free of columns and overhead encumbrances (fig. 17). This area is occupied by 14 drive-in truck bays for the inspection and repair of trucks and tractors, by 2 drivethrough lubrication bays and a drivethrough tractor repair bay. All bays are easily accessible through oversize 16- by 16-foot rollup doors and are served by a 20-ton bridge crane.

One side of the building is occupied by individual repair rooms, each furnished with the specialized tools and equipment for repairing or completely rebuilding particular units. These shops include a welding and metal shop, transmission, brake and differential shop, converter and pump shop, electric shop, and engine repair shop. All shops are furnished with the usual tools and materials, plus equipment for static and dynamic testing of rebuilt units.

The entire shop is arranged to avoid clutter and confusion. Tools and work benches are located along the central wall, and small repair parts and special tools are easily and quickly available from the centrally located tool room and adjoining parts room. Large spare parts are stocked in the nearby general warehouse to avoid crowding. Compressed-air and electric lines are reel mounted to avoid clutter. Grease hoses at the lubrication pits are similarly mounted for the same reason. Provision is made in the lubrication pits for waste oil to flow through a covered drain to a 1,000-gallon-capacity waste-oil sump.

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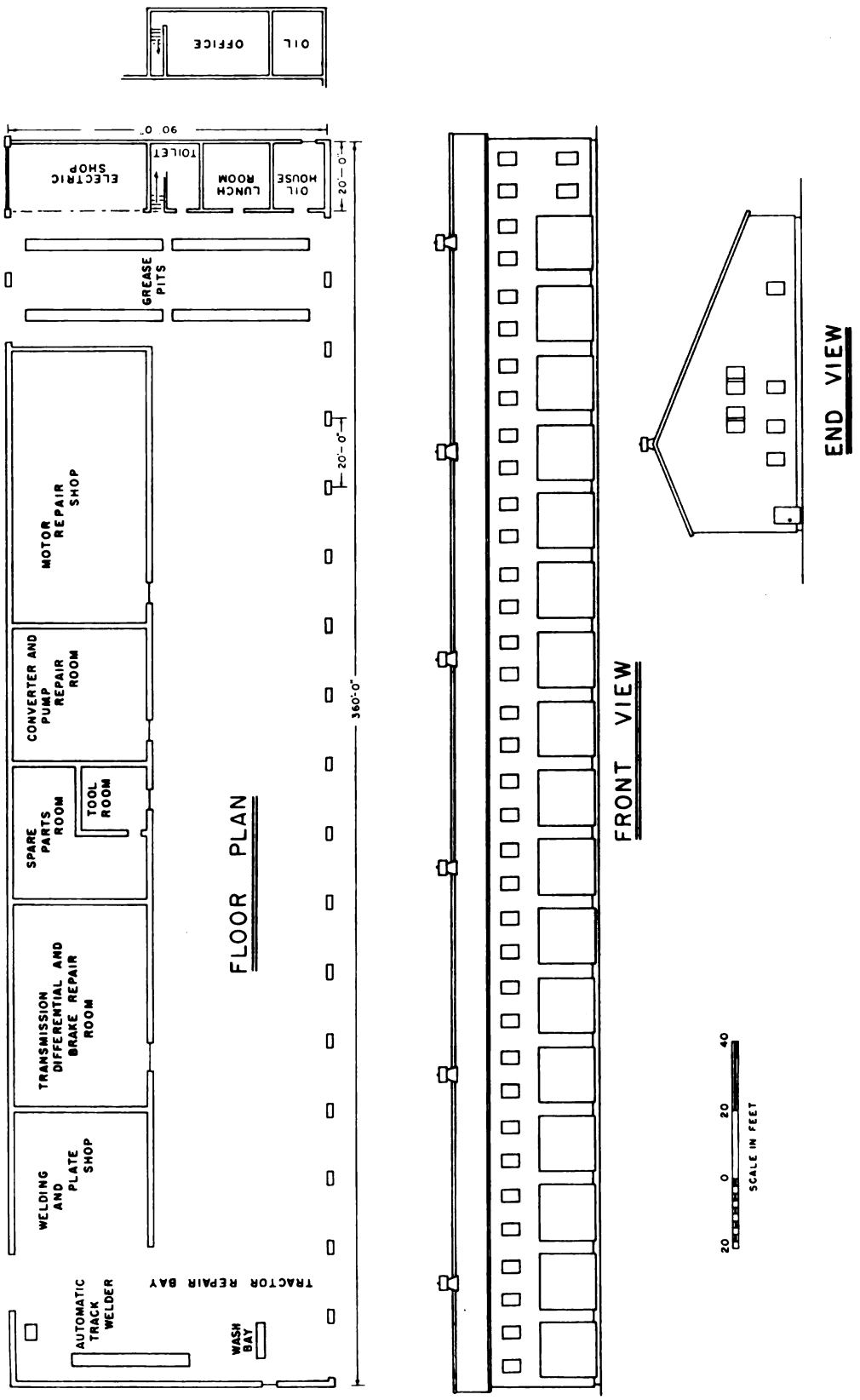

FIGURE 16. - Floor Plan of Garage and Shop.

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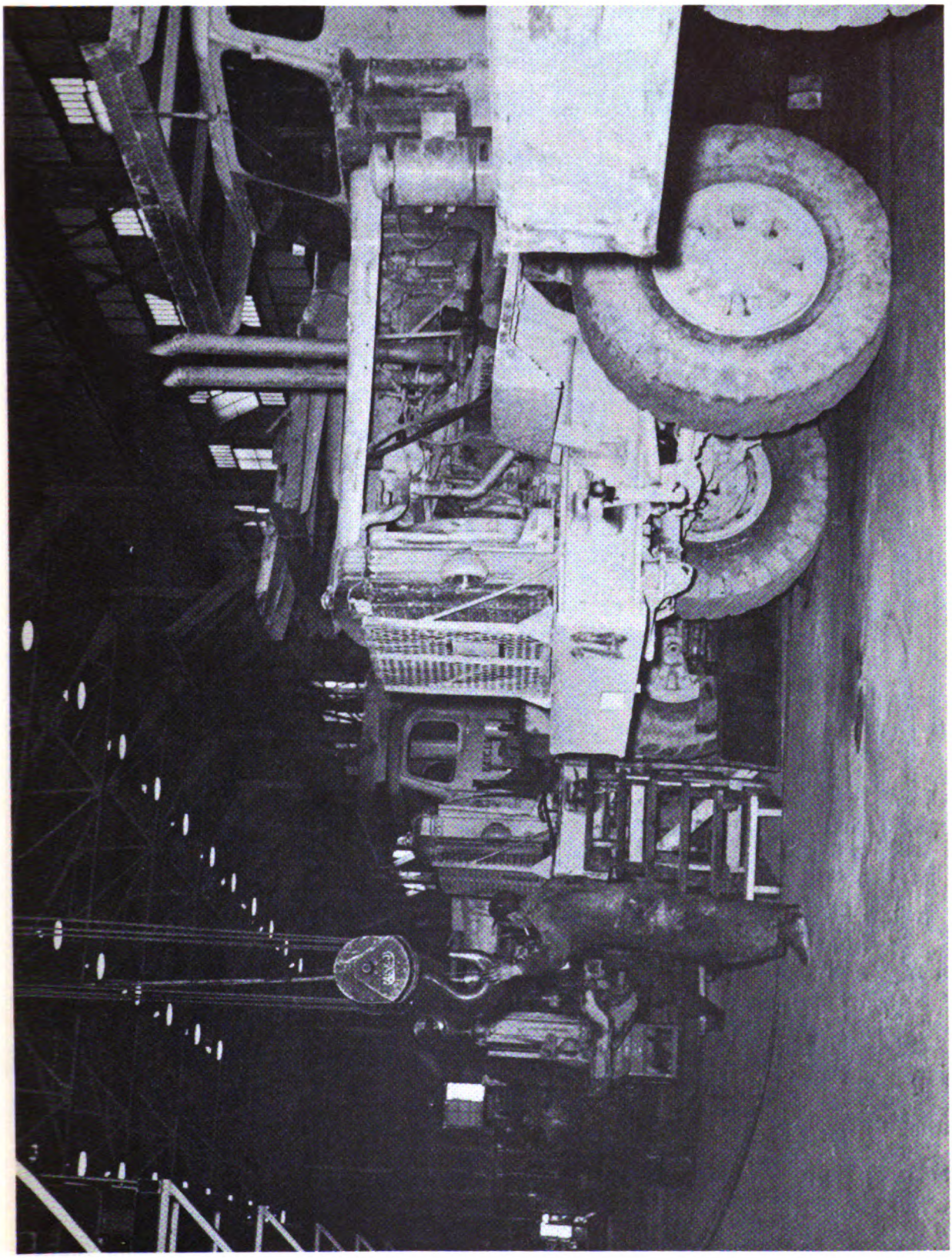

FIGURE 17. - Interior View of Garage.

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Washing, painting, and steam cleaning are done in a separate building located apart from the main garage. Fuel is dispensed from three fueling points, two for diesel oil and one for gasoline, each capable of handling two vehicles simultaneously. Fuel is stored in four aboveground 20,000-gallon diesel oil tanks and two underground 10,000-gallon gasoline tanks.

Other outdoor facilities include a large ramp adjacent to the garage where casual or preliminary repair work can be done to avoid crowding indoor facilities, and a large parking area for idle or crippled equipment (fig. 18). The parking area is equipped with electrical outlets to preheat truck engines for easier starting in cold weather.

ORE-CRUSHING FACILITIES

Temporary

The temporary ore crusher was installed on the east rim of the pit (fig. 9). A built-up dump dock enabled trucks to end-dump directly into a 3- by 4-foot jaw crusher, which crushes to minus-10-inch (fig. 19). Crushed ore was transferred to waiting railroad cars through a tunnel beneath the Meaderville road by a 36-inch conveyor belt (fig. 20). The belt was powered by a 75-horsepower electric motor, which gave a belt speed of 525 feet per minute for a capacity of 1,700 tons per hour. This crusher, set up to handle production from the preliminary pit, was heavily overloaded and was replaced by a permanent crusher and ore-handling system of greater capacity.

Permanent

The permanent crusher and conveyor system is on the south rim of the pit at the 5600 level (fig. 9). Trackside storage bins on the opposite side of U. S. 91 receive crushed ore by an underground conveyor belt through an inclined tunnel beneath the roadway (fig. 21).

The crusher is installed in a concrete revetment with a glory-hole ore pass leading to the conveyor system (fig. 22). The dump slot or receiving bin is a rectangular opening arranged so that three trucks can unload simultaneously. Ore containing timber, rail, and other debris from abandoned underground stopes is cleaned by passing across a wobbler-type grizzly (fig. 23). Debris is removed, and oversize ore discharges to a pan feeder. Ore known to be free of debris bypasses the wobbler and is fed by the pan feeder to a 6- by 14-foot vibrating grizzly, which shunts oversize ore to a 5- by 7-foot jaw crusher. Crusher product and undersize (minus-8-inch) ore from the grizzlies are collected by gravity in a 16-foot-diameter, concrete-lined ore pass, which serves as a 400-ton-capacity surge bin. Crushed ore is withdrawn by a 60-inch pan feeder across a 72-inch picking belt, where remaining debris is removed by hand and by a Dings magnet. The picking belt feeds directly to the main 48-inch conveyor belt. The main belt is 1,038 feet long and has a nominal capacity of 1,800 tons per hour at a speed of 400 feet per minute. It is enclosed by a concrete-lined tunnel for more than half its length as it passes beneath U. S. 91 and several sets of railroad tracks. It emerges 575 feet south of the pit and continues 340 feet to the track-side storage area. Tower-housed feeder

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FIGURE 18. - Aerial View of Garage and Maintenance Area. (A) Wash racks, (B) main garage, (C) warehouse, (D) pit office, (E) parking area.

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FIGURE 19. - Original Crusher Installation.

and tripper belts can divert ore to a 50,000-ton-capacity concrete slab for outdoor storage or to a twin bank of 22 steel storage and loading bins of 5,000 tons total capacity. Stockpiled ore is reclaimed by apron feeders and carried by belt to the loading bins (fig. 24). Ore is drawn from the bins by air-operated guillotine-type chute gates discharging into railroad cars. In present practice cars are loaded two at a time, although as many as five can be loaded simultaneously.

Underground openings for the crusher and conveyor system were constructed by conventional mining methods, but with several unique innovations. The incline housing the conveyor belt was driven 10 by 15 feet in section with trackless equipment, including a 6-yard, Koehring Dumptor, scrubber-equipped, diesel-powered truck and an air-powered, Eimco 630, overcast mucking maching. The bed of the truck proved too high for direct loading from the Eimco bucket, so a short belt loader assembly on wheels was used in conjunction with the regular mucker for loading (fig. 25). Worn drill bits were welded on the mucker crawler pads to provide additional traction on the 12° slope.

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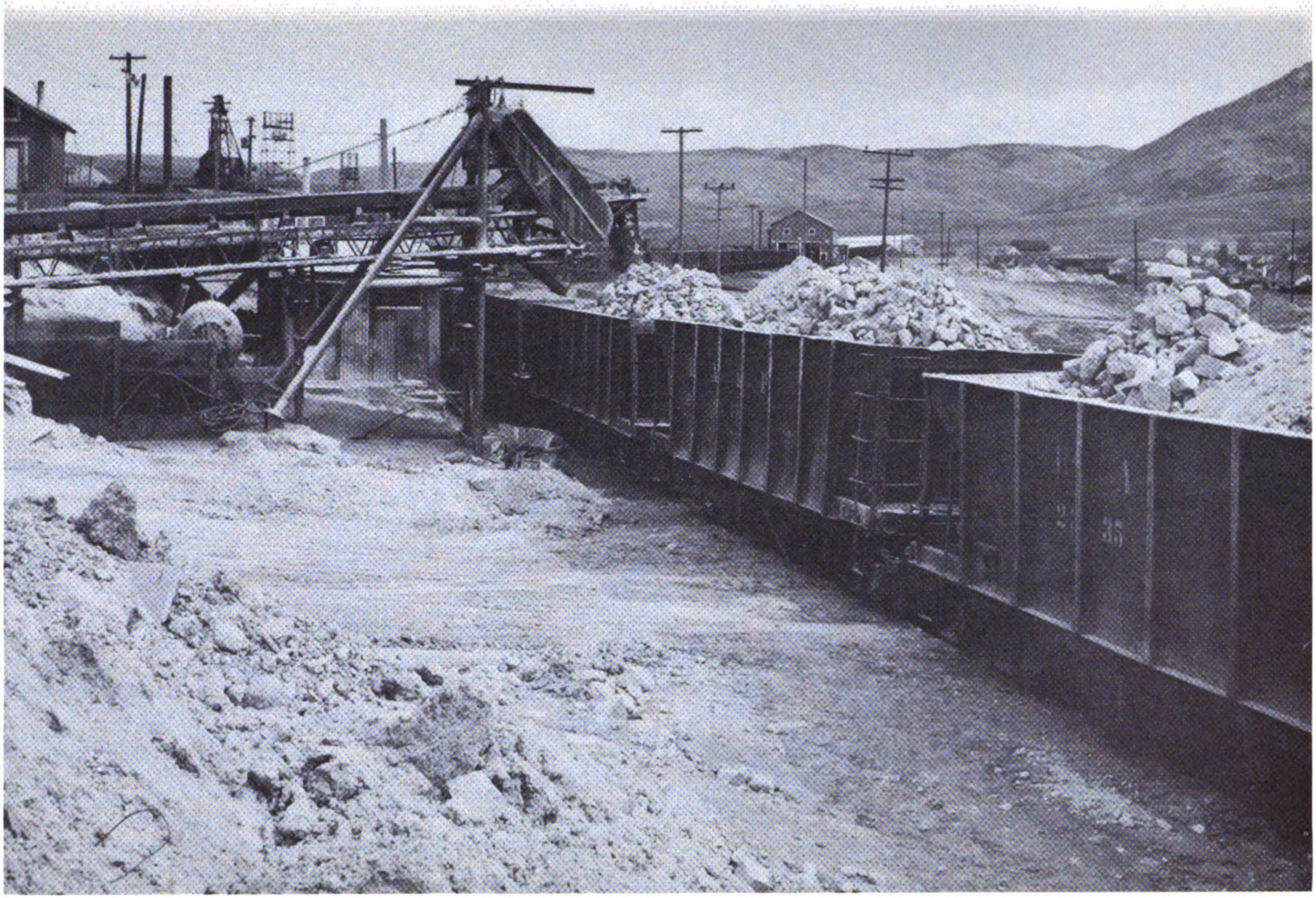

FIGURE 20. - Loading Bottom-Dump Hopper Cars From Original Crusher Belt.

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FIGURE 21. - Aerial View of Ore-Loading Facilities.
Note (A) Leonard shaft, (B) Meaderville, and (C) Berkeley garage in background.

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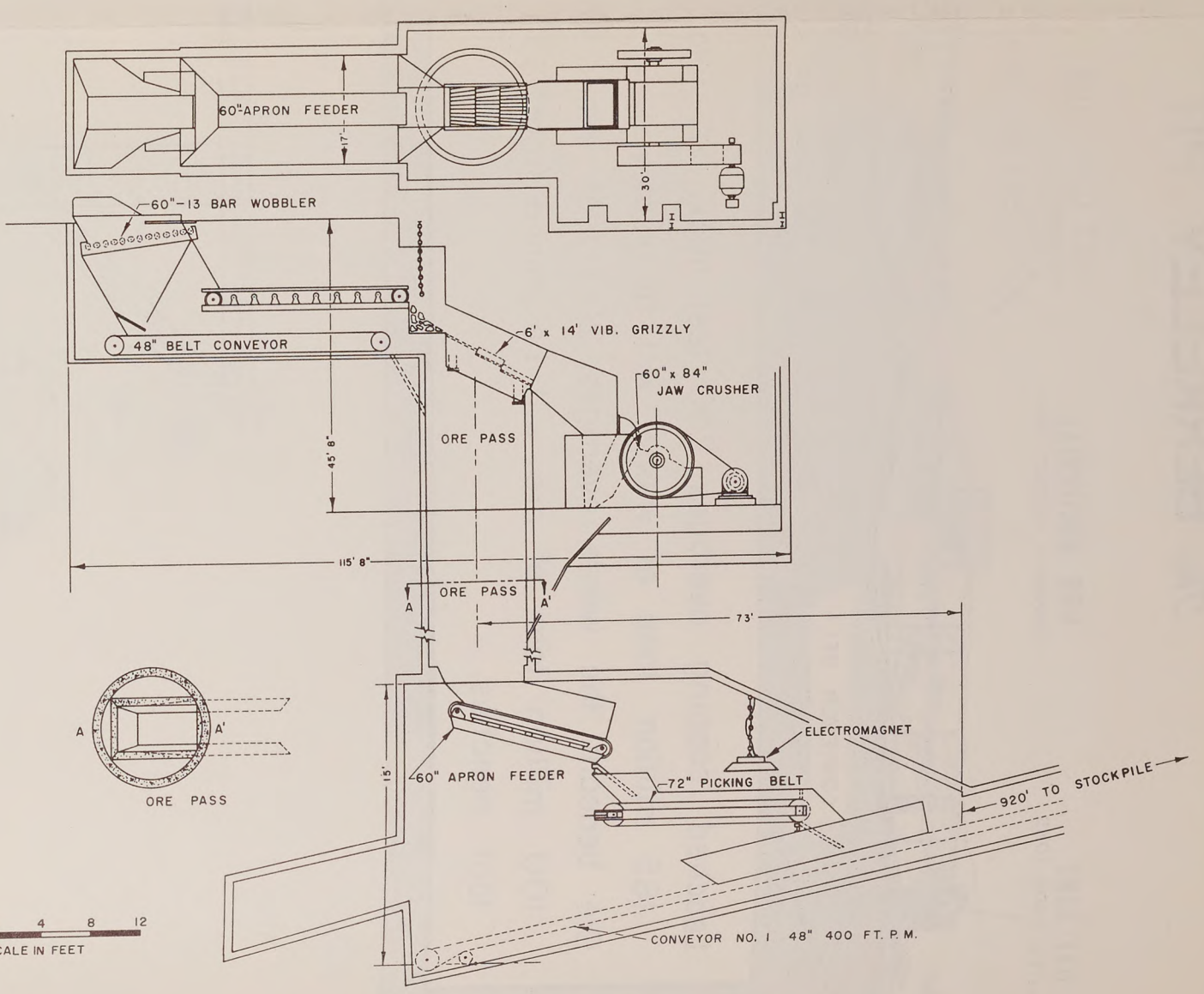

FIGURE 23. - Ore Crusher and Conveyor System.

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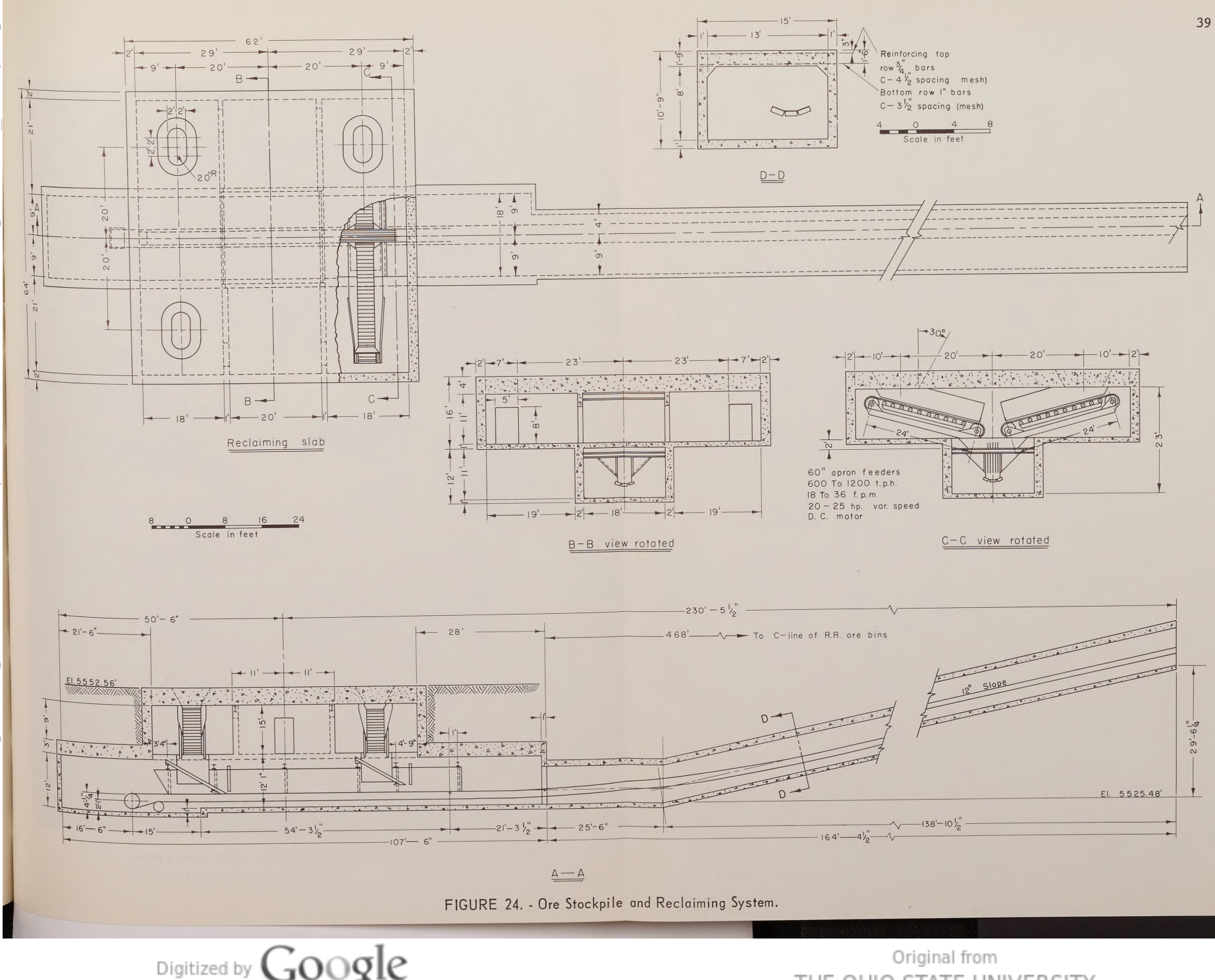

FIGURE 24. - Ore Stockpile and Reclaiming System.

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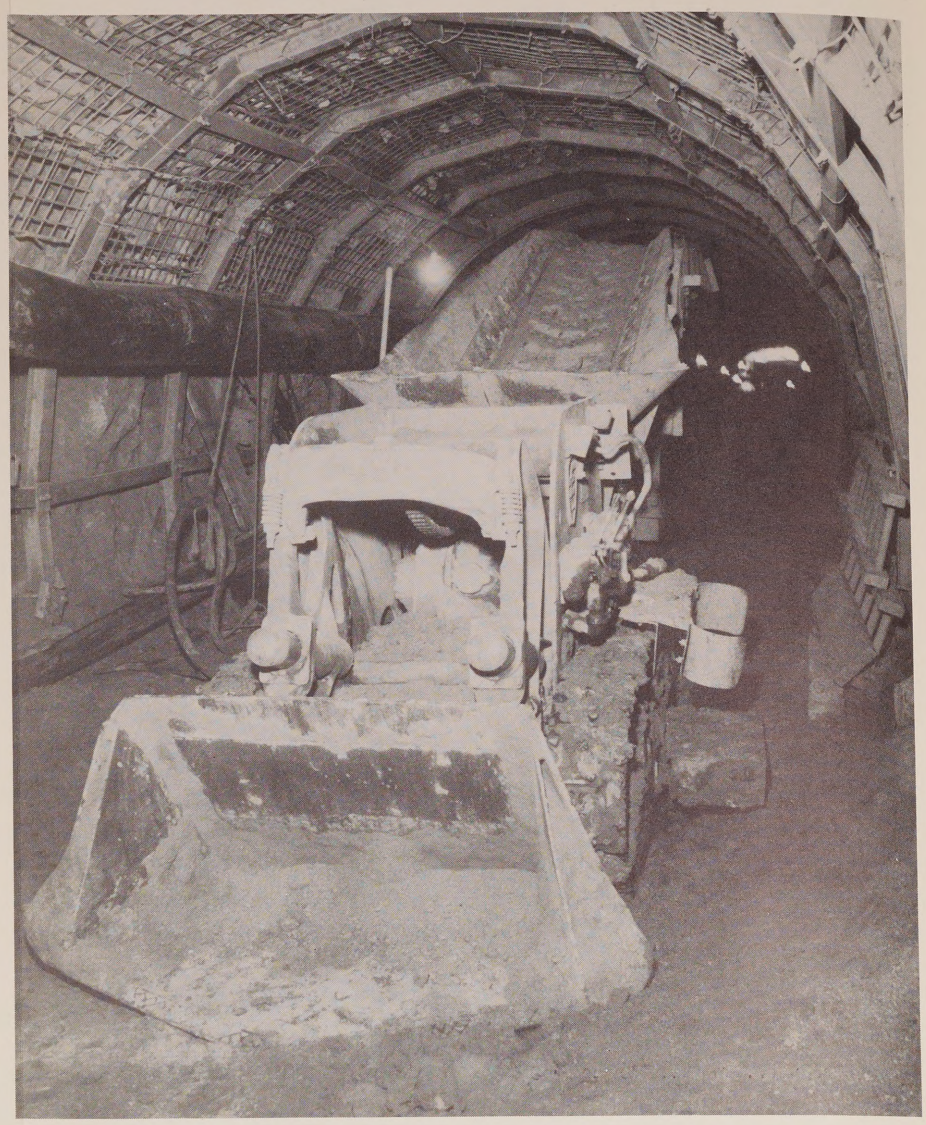

FIGURE 25. - Eimco Loader and Mucker in Conveyor Tunnel.
(Courtesy, The Anaconda Company)

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The entire crusher-conveyor excavation is lined with concrete reinforced with landing mats rock-bolted in place. Preformed steel I-beam sets for the conveyor tunnel were assembled underground and lagged in 20-foot sections with 1-inch tongue-and-groove lumber. Premixed concrete was forced behind the lagging with a conventional pumpcrete machine (fig. 26). The sill and several feet of wall were poured first and allowed to set up for several hours to avoid excessive hydrostatic pressure. The upper sides and back were then pressure-poured through a 6-inch pipe in the back lagging. Several sections were poured directly from the surface through 6-inch drill holes.

The lower part of the crusher installation was excavated from the tunnel. An incline was driven to the back and slashed out to room width. Second and third top slices were taken from the floor until the room assumed full size. The upper part of the crusher installation was constructed in a glory hole excavated from the surface. The raise connecting the two sections and forming the ore-pass surge bin was driven pilot size and slabbed out to 18 feet diameter.

RAIL TRANSPORTATION

Ore is hauled 26 miles by rail for processing at The Anaconda Reduction Works at Anaconda, Mont. The original crusher on the east side of the pit was served by the Berkeley siding of the Butte, Anaconda and Pacific Railroad. The switch, on a minus-3-percent grade to facilitate manual car spotting, had a capacity of 14 cars, which were loaded directly from the crusher by conveyor belt.

The permanent trackside ore storage and loading area is served by the Northern Pacific Railroad, whose right-of-way bypasses downtown Butte; mainline haulage from Durant to Anaconda is on Butte, Anaconda and Pacific tracks. Ore trains of 30 or more cars make 7 to 9 trips daily; ore shipments will increase to an eventual maximum of more than 300 cars per day. The Butte, Anaconda and Pacific Railroad, which transports all of Butte's production, will replace part of its rolling stock with 200 new ore cars and 4 new diesel engines to accommodate increased traffic resulting from Berkeley-pit production. The new cars are 80-ton, flat-bottom gondolas replacing bottom-dump hopper cars. Flat-bottom cars are emptied at the smelter by a rotary tipple.

PRODUCTION

Ore production from January to March 1958 averaged 18,820 tons per day on a three-shift-per-day, 5-day-week basis. During the same period 58,100 tons of waste and 4,600 tons of leach ore were mined daily. Eventual weekly ore production may reach 192,000 tons.

Production statistics and distribution of mining costs are summarized in tables 7 - 10, and table 11 is an inventory of the major equipment used at the Berkeley pit.

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FIGURE 26. - Pouring Concrete for Reinforced Tunnel Lining.

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TABLE 7. - Operation and production statistics

	All
Drilling:	
Total feet drilled	38,520
Operating shifts	91
Feet per shift	423.30
Feet per man-shift	214.00
Blasting:	
Tons broken	1,847,703
Pounds explosive	290,644
Tons per pound of explosive	6.3573
Tons per foot of hole drilled	47.967
Tons per man-shift	17,766.38
Loading:	
Tons loaded	2,177,333
Operating shifts	282
Tons per shift	7,721.04
Tons per man-shift	2,451.95
Truck haulage:	
Tons hauled	2,177,333
Operating shifts	2,115.75
Tons per truck shift	1,029.11
Tons per man-shift	885.09
Average daily production: 1/	
Ore, tons	6,353
Waste, do.	8,200
Period: January 1958	
Production: Ore	464,610
Waste	1,712,723
Total	2,177,333 (wet)

1/ Per 8-hour shovel-shifts.

TABLE 8. - Production, in terms of labor

	Man-hours per 1,000 tons		
	Mining	Dev	All
Labor:			
Drilling	0.787	0.627	0.661
Blasting	.405	.376	.382
Loading	3.606	3.170	3.263
Haulage	8.217	9.260	9.039
Dump maintenance	-	1.738	1.367
Road maintenance	.468	.588	.562
Ore-handling system	7.542	-	1.609
Supervision	3.506	3.505	3.505
Service and miscellaneous	1.474	1.473	1.473
Repairs to capital equipment	6.505	4.677	5.067
Total	32.510	25.414	26.928
Tons per man per shift	246.1	314.8	297.1
Period: January 1958			
Production: Ore 464,610			
Waste 1,712,723			
Total 2,177,333 tons (wet)			

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TABLE 9. - Percentage distribution of mining and development costs

	Labor	Fuel lubrication	Tires	Explosives	Other supplies	Service	Total	Percentage of operating expense[2]	Apportionment[1] Mining	Apportionment[1] Development
Blasthole drilling	55.60	2.12	-	-	42.48	-	100.00	1.72	25.40	74.60
Blasting	8.30	.22	-	91.47	.01	-	100.00	6.61	22.64	77.36
Loading	64.41	6.99	-	-	28.60	-	100.00	7.90	23.58	76.42
Truck haulage	41.20	19.92	36.75	-	2.13	-	100.00	33.98	19.40	80.60
Dump maintenance	91.02	6.80	-	-	2.18	-	100.00	2.15	-	100.00
Road maintenance	80.85	11.48	3.48	-	4.19	-	100.00	1.07	17.79	82.21
Ore-handling system	89.18	3.27	-	-	7.55	-	100.00	2.47	100.00	-
Service and miscellaneous	13.96	6.13	2.07	-	8.72	69.12	100.00	8.15	21.34	78.66
Superintendence, clerical, technical ...	100.00	-	-	-	-	-	100.00	5.53	21.34	78.66
Repairs to capital equipment	34.28	-	-	-	65.72	-	100.00	22.82	27.40	72.60
Power - electric	-	-	-	-	100.00	-	100.00	.97	32.32	67.68
Sundry expenses	56.30	-	-	-	43.70	-	100.00	1.82	11.77	88.23
Sundry labor expenses[3].	100.00	-	-	-	-	-	100.00	4.81	21.34	78.66
Percentage of total operating expense[3] ...	45.94	8.22	12.69	6.04	21.46	5.63	-	100.00	23.78	76.22

1/ Allocation made on direct charges where possible; elsewhere on proportionate activity.
2/ Does not include deferred development, amortization, taxes, and general office charges.
3/ Includes retirement contributions, holiday and vacation allowances, and similar expenses.

Period: January 1958			Percent
Production:	Ore	464,610	21.34
	Waste	1,712,723	78.66
	Total	2,177,333 tons (wet)	100.00

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TABLE 10. - Cost distribution of direct supplies[1/]

Tires	24.47
Fuel and lubrication	16.53
Tools and parts	35.11
Explosives	11.65
Electricity	1.86
Sundry and miscellaneous	10.38
	100.00

1/ Percentage of total cost of power and supplies.

TABLE 11. - Inventory of equipment

Item	Quantity	Size or capacity	Model	Manufacture	Remarks
Shovel	5	6-yd.	150-B	Bucyrus-Erie	
Do.	1	3-yd.	71-B	do.	
Tractor	4		TD-24	International	Dozer-mounted crawler.
Do.	2		D-8	Caterpillar	Do.
Do.	4		D-6	do.	Do.
Drill, rotary	3	9-in.	40-R	Bucyrus-Erie	
Do.	1	6-in.	225-AST	do.	
Truck, ore	25	34-ton	4-FFD	Euclid	Dual-drive, twin 210-hp. diesel engines.
Do.	18	34-ton	LRV-SW	Mack	Dual drive, 400-hp. diesel engine.
Truck, tank	2	4,010-gal.		do.	Sprinkler.
Do.	1	4,000-gal.		GMC	Fuel.
Truck, lowboy	1	100-ton		Mack	
Truck, flat-bed	1			GMC	Mobile grease rack.
Do.	1			do.	Repair truck, equipped with air compressor, arc welder and mono-rail crane.
Bus	2	40-pass.		Chevrolet	
Grader	2			Allis Chalmers	Motor patrol.
Do.	2			Caterpillar	
Truck, flat-bed	1			GMC	Powder truck.
Crane, mobile	2	30-ton		P & H	
Truck, pickup	3	1/2-ton		Chevrolet	
Truck, panel	1	1/2-ton		Dodge	
Passenger vehicle	4	Jeep 4-wheel drive station wagon		Willys-Overland	4-wheel drive.

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